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## SIR CHARLES GOODEVE, O.B.E., D.Sc., F.R.S.

SIR CHARLES GOODEVE was born in Canada on 21st February, 1904. In 1919, he entered the University of Manitoba, where he graduated with honours in chemistry and physics in 1925 and obtained an M.Sc. degree in electrochemistry in 1927. During the years 1922-1927 he was Demonstrator and Assistant Lecturer in Chemistry at the University of Manitoba, and was then awarded an 1851 Exhibition Scholarship for studies in England. In 1928 he was awarded the Scientific Club of Manitoba Prize and the Plummer Gold Medal of the Engineering Society of Canada.

At the age of twenty-five he became Assistant Lecturer at University College, London, and a year later, in 1930, was appointed Lecturer in Physical Chemistry. In 1936 he obtained his D.Sc. degree and in the following year became Reader in Chemistry.

Amongst other activities at that time Sir Charles served as a Member of Council of the Faraday Society from 1935 to 1938 and was a member of the Ink Advisory Panel of the Printing and Allied Trades Research Association in 1937. He also sat on the Publication Committees of the Chemical Society and the Faraday Society and was a member of the British Standards Institution Committee on Symbols.

On the outbreak of war Sir Charles was commissioned as a Lieutenant-Commander, R.N.V.R., and was stationed at H.M.S. Vernon, where he worked on the development of counter-measures to the German magnetic mine. In 1940 he was promoted to Commander, R.N.V.R., and was posted to the Admiralty, where he ultimately set up the Department of Miscellaneous Weapons Development of which he became Technical Head. In 1942 he was appointed Assistant Controller for Research and Development, becoming Deputy Controller in 1944.

In 1945 Sir Charles became Director of the British Iron and Steel Research Association, which was formed to carry on the work of the Iron and Steel Industrial Research Council. He was elected an Honorary Member of Council of the Iron and Steel Institute in 1945.

His war services were recognized by his appointment as an Officer of the Most Excellent Order of the British Empire in 1941, by the Knighthood which was conferred upon him in January, 1946, and also, in June, 1947, by the presentation of the American Medal of Freedom with Silver Palm, for his services in building up the liaison between the U.S. Navy Department and the Admiralty, and for other services to the Allies.

**Sir Charles Goodeve, O.B.E., D.Sc., F.R.S.**
**Director, British Iron and Steel Research Association**

IRON AND STEEL
INSTITUTE PAPERS

PLANT DESIGN · MANUFACTURE · RESEARCH · DEVELOPMENT

# SECOND HATFIELD MEMORIAL LECTURE

## Steels for Use at Elevated Temperatures*

*By C. Sykes, D.Sc., F.R.S.*†

As Dr. Hatfield's successor at the Brown-Firth Research Laboratories, the honour of being called upon to give the Second Memorial Lecture has given me great pleasure.

The choice of subject for a lecture of this type is not always an easy matter ; the present subject was chosen after some deliberation, for two main reasons : firstly, it is one in which the late Dr. Hatfield was an acknowledged pioneer and expert, and secondly, it is of considerable topical interest in view of present engineering trends towards higher steam temperatures, and to the use of the gas turbine.

In 1938 Dr. Hatfield[1] read a paper summarizing the applications and properties of a number of heat-resisting steels which had been developed since the discovery of stainless steel in 1913. The paper included creep and scaling data, and an extensive bibliography of this subject.

Subsequent to this date, the Brown-Firth Research Laboratories have been developing ferritic and austenitic steels for high temperature work and have been examining methods of production which could be used to work the new materials into the various products required industrially. In this paper it is proposed to describe certain features of this experimental and development work, much of which was either carried out under Dr. Hatfield's direction or initiated by him. The paper is restricted to the following main items :

1. The properties of large forgings in ferritic steels.
2. The development of R. ex 78 and similar steels.
3. Large austenitic steel forgings.

No attempt will be made to give a critical review of the subject of steels for use at high temperatures. This would be a formidable task at any time ; but at the present juncture, due to the great stimulus provided by the jet engine during and subsequent to the war, the field is changing rapidly. Considerable progress has been made, but until more authoritative data is available together with long-term service experience, it seems premature to endeavour to assess the relative merits of the various classes of steel developed both in this country and in the U.S.A. Sufficient data will be given on the various steels discussed, to enable comparisons to be made with such data as is available in the literature on other alloy steels and non-ferrous materials. In addition, a bibliography of papers dealing with the subject, and appearing after 1938, is appended.

### (1) The Properties of Large Forgings in Ferritic Steels

#### (a) *General*

A good deal of experience is now available relating to the use of carbon and carbon–molybdenum steels at temperatures up to 500° C. These ' standard ' materials are generally used in the normalized and stress-relieved condition, say of 25–35 tons/sq. in. ultimate tensile, and cover a wide range of applications ; from steam pipes to rotor forgings. For certain purposes, for example, rotor forgings and pressure vessels, many designers prefer material with improved mechanical properties. Although these standard materials can be

* Received and presented 14th May, 1947.
† The Brown-Firth Research Laboratories.

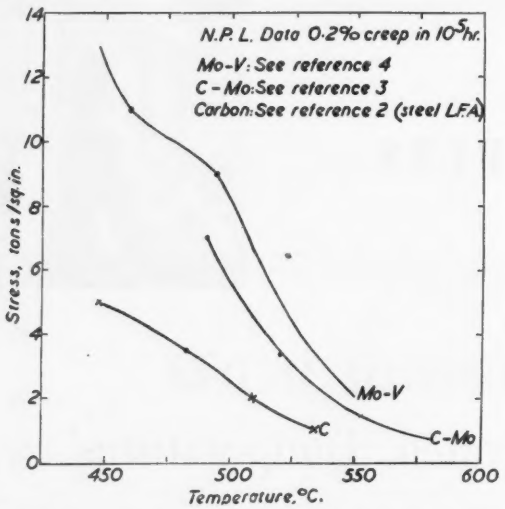


FIG. 1—Typical long-term creep curves of carbon, carbon–molybdenum, and molybdenum–vanadium steels

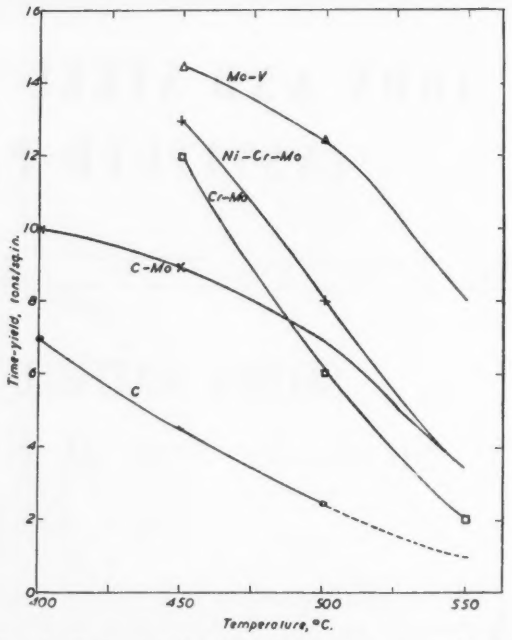


FIG. 2—Representative time-yield creep curves for the same class of steel as in Fig. 1

heat-treated to give superior properties, such treatments, due to the low hardenability of these steels, can only be applied to quite small ruling sections ; and for large forgings, necessitating ingot sizes up to 150 tons, it is necessary to use more highly alloyed steels in order to achieve satisfactory uniformity of properties throughout the mass. The materials to which I shall refer in this section are the 2–2½%-nickel–chromium–molybdenum steel and the 3%-chromium–molybdenum steel, and they are primarily used in the hardened and tempered condition in the form of large forgings.

In considering the merits of the more highly alloyed steels, perhaps the most useful procedure is to compare their properties with those of the carbon and carbon–molybdenum steels. As far as the normal tensile properties are concerned this is straight forward, but on some of the alloy steels the creep data available is by no means as extensive as that available on the standard materials, and it is necessary, therefore, to describe briefly the procedure adopted in assessing the relative creep performance of the materials.

Since it has not proved practicable to carry out long-term creep tests, *i.e.*, up to 10,000 hr., on the great variety of steels under investigation, it is our custom to compare ferritic steels on the basis of their Hatfield time-yield stress, supplementing this information with additional tests lasting up to 500 hr. or so. The time-yield stress

TABLE I—*Physical Properties of Acid-Open-Hearth Carbon-Steel Shaft*

| Temperature of Test | Test Position | Direction of Test | Physical Properties | | | | | | Remarks |
|---|---|---|---|---|---|---|---|---|---|
| | | | Proof Stress, tons/sq. in. | | | Maximum tons/sq. in. | Elongation, % | Reduction of Area, % | |
| | | | 0·10% | 0·20% | 0·50% | | | | |
| Atmospheric | Shaft end | Longitudinal | ... | ... | 21·6 | 38·6 | 29 | 48 | Ingot weight : 49 tons. Diameter of body of forging : 28 in. Composition, %: C, 0·39; Si, 0·23; Mn, 0·79; S, 0·030; P, 0·022; Ni, 0·41; Cr, 0·19. Heat-treatment: Normalized from 875° C., tempered at 625° C. |
| | Body end, outside | Tangential | ... | ... | 22·0 | 39·0 | 25 | 32 | |
| | Body end, outside | Radial | ... | ... | 22·0 | 38·8 | 21 | 25 | |
| | Core, centre body | Longitudinal | 19·2 | 19·4 | 19·8 | 39·4 | 29·5 | 45 | |

TABLE II—*Physical Properties of Basic Electric Carbon–Molybdenum-Steel Shaft*

| Temperature of Test | Test Position | Direction of Test | Physical Properties | | | | | | | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Proof Stress, tons/sq. in. | | | Maximum Stress, tons/sq. in. | Elongation, % | Reduction of Area, % | Izod, ft. lb. | |
| | | | 0·10% | 0·20% | 0·50% | | | | | |
| Atmospheric | Shaft end | Longitudinal | ... | ... | 24·2 | 38·2 | 22 | 49 | ... | Ingot weight : 21 tons. Dia. of body of forging : 24 in. Composition, % : C, 0·32 ; Si, 0·23 ; Mn, 0·55 ; S, 0·013 ; P, 0·012 ; Ni, 0·32 ; Cr, 0·09 ; Mo, 0·63. Heat-treatment : Normalized from 900° C., tempered 645° C. |
| | Body end, outside | Tangential | ... | ... | 22·6 | 36·4 | 26 | 48 | ... | |
| | Body end, outside | Radial | ... | ... | 23·6 | 38·0 | 18·5 | 45 | ... | |
| | Core, centre body | Longitudinal | 17·5 | 17·9 | 18·2 | 33·2 | 31·5 | 51 | 16, 15, 12 | |

is defined as that stress which produces an average rate of strain of $10^{-6}$ in./in./hr. between the 24th and 72nd hour of the creep test. In addition the elongation during the initial 24 hr. must not exceed 0·5%. It will appear that the steels under review have creep properties which lie in the range between those of carbon steel and those of molybdenum–vanadium steel. Due to the excellent and thorough work carried out for the B.E.A.I.R.A. by the National Physical Laboratory, long-term creep data is available on carbon,[2] carbon–molybdenum,[3, 4] and molybdenum–vanadium[4] steels, typical curves being given in Fig. 1. Representative time-yield values are plotted in Fig. 2, for the same classes of steel. By comparing the time-yield values of the alloy steels with those of the 'standard' materials, *see* Fig. 2, a reasonable approximation to their merits is achieved, and by using Fig. 1 in addition, the long-term creep behaviour may be assessed.

### (b) *Mechanical Properties*

*At Room Temperatures*

Considering first, Tables I, II, III, and IV (*a*), which refer to the materials in the normalized and tempered condition, the alloy steels give much higher proof properties than either the carbon or the carbon–molybdenum steels. The ductility, in comparable positions, of the nickel–chromium–molybdenum steel and the chromium–molybdenum steel is very similar to that of the carbon and carbon–molybdenum steels. The 3%-chromium–molybdenum steel shows a very high degree of uniformity in proof properties throughout the mass of the forging, and is superior in this respect to the nickel–chromium–molybdenum steel due to its improved hardenability. Both give higher proof properties at the centre than the standard steels.

Reasonable uniformity in properties in the 40–45 tons/sq. in. ultimate tensile strength range is obtained with the nickel–chromium–molybdenum steel up to about 35 in., and the 3%-chromium–molybdenum steel up to 55 in.

The data given in Table IV (*b*) brings out clearly the improvement in ductility obtained by oil hardening the 3%-chromium–molybdenum as distinct from air hardening, similar improvement would no doubt be obtained on the nickel–chromium–molybdenum steel.

Table IV (*c*) gives data for the 3%-chromium–molybdenum steel in the oil-hardened and tempered condition when produced from electric furnace steel ; excellent ductility and uniformity of properties are obtained.

*At Elevated Temperatures*

On the basis of the time-yield values (Fig. 2) it will be seen that the nickel–chromium–molybdenum steel is somewhat superior to the 3%-chromium–molybdenum steel. At 450° C., both materials are very much superior to plain carbon steel, and intermediate between molybdenum steel and molybdenum–vanadium steel. At 500° C. and 550° C. the time yield of both steels is very similar to that of the straight molybdenum steel.

The time-yield values plotted in Fig. 2 for the nickel – chromium – molybdenum and 3%-chromium–molybdenum steels are representative of a number of observations on test pieces cut from forgings : as is usual with creep determinations, there is some 'spread' in the values, but a variation of ± 15% in stress covers the bulk of

TABLE III—*Physical Properties of Acid-Open-Hearth Nickel–Chromium–Molybdenum-Steel Shaft*

| Temperature of Test | Test Position | Direction of Test | Physical Properties | | | | | | | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Proof Stress, tons/sq. in. | | | Maximum Stress, tons/sq. in. | Elongation, % | Reduction of Area, % | Izod, ft. lb. | |
| | | | 0·10% | 0·20% | 0·50% | | | | | |
| Atmospheric | Mid-body, outside | Longitudinal | 31·0 | 32·2 | 34·2 | 44·0 | 21·5 | 38 | 30, 30, 30 | Ingot weight : 36 tons. Dia. of body of forging : 34 in. Composition, % : C, 0·25; Si, 0·21 ; Mn, 0·54 ; S, 0·030 ; P, 0·027 ; Ni, 2·23 ; Cr, 0·38 ; Mo, 0·43. Heat-treatment : Air hardened from 850° C., tempered at 620° C. |
| | Mid-body, core | Longitudinal | 24·5 | 25·8 | 27·0 | 39·4 | 14 | 18 | 40, 44, 44 | |
| | Mid-body, outside | Tangential | 31·0 | 32·7 | 34·4 | 44·6 | 22 | 40 | 24, 15, 20 | |
| | Mid-body, near centre | Tangential | 22·8 | 24·0 | 25·6 | 37·8 | 17 | 30 | 30, 34, 36 | |
| | Mid-body, outside | Radial | 28·9 | 30·0 | 31·5 | 42·4 | 21·5 | 43 | 25, 25, 20 | |
| 400° C. | Mid-body, core | Longitudinal | 19·7 | 22·2 | 24·8 | 33·9 | 23 | 51 | ... | |
| | Mid-body, outside | Tangential | 25·3 | 28·1 | 31·1 | 38·1 | 23 | 47 | ... | |
| | Mid-body, near centre | Tangential | 16·7 | 19·2 | 22·7 | 31·0 | 23 | 51·5 | ... | |

TABLE IV (*a*)—*Physical Properties of Acid-Open-Hearth Chromium–Molybdenum-Steel Shaft*

| Temperature of Test | Test Position | Direction of Test | Physical Properties | | | | | | | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Proof Stress, tons/sq. in. | | | Maximum Stress, tons/sq. in. | Elongation, % | Reduction of Area, % | Izod (mean) ft. lb. | |
| | | | 0·10% | 0·20% | 0·50% | | | | | |
| Atmospheric | Mid-body : Outside | Tangential | 35·9 | 36·5 | 37·2 | 47·6 | 20 | 47 | 23 | Ingot weight : 36 tons. Dia. of forging : 31 in. Composition, %: C, 0·28; Si, 0·25; Mn, 0·56 ; S, 0·035 ; P, 0·022 ; Ni, 0·20 ; Cr, 3·26 ; Mo, 0·41. Heat-treatment : Air hardened from 900° C., tempered at 660° C. |
| | Midway | Tangential | 34·8 | 35·7 | 36·4 | 47·0 | 12 | 28 | 23 | |
| | Near centre | Tangential | 34·6 | 35·6 | 36·2 | 46·4 | 16 | 33 | 19 | |
| | Core | Longitudinal | 33·6 | 34·4 | 35·2 | 46·4 | 25 | 61 | ... | |
| 400° C. | Mid-body : Outside | Tangential | 29·8 | 30·8 | 32·3 | 38·4 | 17·5 | 55 | ... | |
| | Midway | Tangential | 28·2 | 30·2 | 32·5 | 38·8 | 14·5 | 34 | ... | |
| | Near centre | Tangential | 29·1 | 30·6 | 32·5 | 38·3 | 20 | 43 | ... | |
| | Core | Longitudinal | 28·5 | 30·2 | 31·8 | 37·9 | 20 | 61 | ... | |
| 455° C. | Mid-body : Outside | Tangential | 28·0 | 29·5 | 31·2 | 35·6 | 21 | 56·5 | ... | |
| | Midway | Tangential | 27·8 | 29·2 | 31·1 | 35·6 | 19 | 46 | ... | |
| | Near centre | Tangential | 27·6 | 29·2 | 31·4 | 35·2 | 20 | 49 | ... | |

TABLE IV (*b*)—*Physical Properties of Acid-Open-Hearth Chromium–Molybdenum-Steel Shaft*

| Temperature of Test | Test Position | Direction of Test | Physical Properties | | | | | | | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Proof Stress, tons/sq. in. | | | Maximum Stress, tons/sq. in. | Elongation, % | Reduction of Area, % | Izod, ft. lb. | |
| | | | 0·10% | 0·20% | 0·50% | | | | | |
| Atmospheric | Shaft end, top, outside | Longitudinal | 34·5 | 35·2 | 36·0 | 46·8 | 24 | 67 | 40, 54, 60 | Ingot weight : 21½ tons. Dia. of body of forging : 24 in. Composition, % : C, 0·28; Si, 0·23; Mn, 0·58; S, 0·033; P, 0·024; Ni, 0·21; Cr, 3·15; Mo, 0·42. Heat-treatment : Oil-hardened from 890° C., tempered at 675° C. |
| | Shaft end, bottom, outside | Longitudinal | 30·0 | 32·0 | 33·0 | 43·0 | 28 | 70 | 78, 73, 47 | |
| | Mid-body | Radial | 33·0 | 34·0 | 34·8 | 44·6 | 22 | 50 | 31, 30, 30 | |
| | Mid-body, outside | Tangential | 33·9 | 34·5 | 35·0 | 45·4 | 23 | 56 | 41, 34, 40 | |
| | Mid-body, near centre | Tangential | 33·1 | 33·7 | 34·7 | 43·4 | 22 | 52 | 40, 41, 30 | |
| | Mid-body, core | Longitudinal | 31·4 | 33·1 | 35·0 | 43·8 | 26 | 67 | 57, 63, 87 | |
| 400° C. | Mid-body, outside | Tangential | 28·1 | 29·3 | 31·0 | 37·3 | 18·5 | 51 | ... | |
| | Mid-body, near centre | Tangential | 26·7 | 28·2 | 30·5 | 35·0 | 18 | 49 | ... | |
| | Mid-body, core | Longitudinal | 27·5 | 29·1 | 30·6 | 35·3 | 18·5 | 64 | ... | |
| 455° C. | Mid-body, outside | Tangential | 26·9 | 28·3 | 30·2 | 34·4 | 22·5 | 51 | ... | |
| | Mid-body, near centre | Tangential | 27·2 | 28·5 | 29·8 | 34·1 | 18 | 51 | ... | |
| | Mid-body, core | Longitudinal | 26·2 | 27·7 | 29·4 | 32·3 | 24 | 67 | ... | |

TABLE IV (*c*)—*Physical Properties of Electric Arc Chromium–Molybdenum Steel*

| Temperature of Test | Test Position | Direction of Test | Physical Properties | | | | | | | | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Proof Stress, tons/sq. in. | | | | Maximum, Stress, tons/sq. in. | Elongation, % | Reduction of Area, % | Izod, ft. lb. | |
| | | | 0·05% | 0·10% | 0·20% | 0·50% | | | | | |
| Atmospheric | Body end | Tangential | ... | ... | 38·8 | 39·8 | 50·8 | 23 | 65 | 68, 41, 50 | Ingot weight : 25 tons. Dia. of body 28¾ in. Composition, % : C, 0·29; Si, 0·23; Mn, 0·58; S, 0·006; P, 0·014; Ni, 0·37; Cr, 3·31; Mo, 0·57. Heat-treatment : Oil-hardened 900° C., tempered 630° C. |
| | Body end | Radial | ... | ... | 39·4 | 40·0 | 51·2 | 22 | 64 | 40, 33 | |
| | Core, mid body | Longitudinal | ... | ... | 37·2 | 38·0 | 48·0 | 24 | 63 | ... | |
| 400° C. | Core, mid-body | Longitudinal | 27·6 | 29·3 | 30·6 | 32·4 | 37·9 | 19 | 51 | ... | |

TABLE V—*Creep Strain in 500 hr. under a Stress of 15·7 tons/sq. in. at 450° C.*

| Direction of Test | Test Position | Creep Strain, % | | | | |
|---|---|---|---|---|---|---|
| | | No. 1 | No. 2 | No. 3 | No. 4 | No. 5 |
| | | 3%-Cr–Mo | 3%-Cr–Mo | Ni–Cr–Mo | 3%-Cr–Mo | 3%-Cr–Mo |
| Longitudinal | Outside | 0·16 | ... | 0·07<br>0·05 | ... | ... |
| | Mid-body | 0·12 | ... | 0·05 | ... | ... |
| | Near centre | 0·52 | 0·23 | 0·05<br>0·04 | ... | ... |
| Transverse | Outside | ... | 0·30 | 0·035 | ... | 0·33, 0·20 |
| | Mid-body | 0·19 | ... | ... | 0·17, 0·30, 0·14 | ... |
| | Near centre | ... | 0·43 | 0·035 | ... | ... |
| Radial | Outside | 0·20 | | ... | ... | ... |
| | Mid-body | ... | | ... | ... | ... |
| | Near centre | 0·23 | | 0·04 | ... | ... |
| Condition | | Oil-hardened and tempered | Air-hardened and tempered | Air-hardened and tempered (four forgings) | Air-hardened and tempered (three forgings) | Oil-hardened and tempered (two forgings) |
| Steel | | Acid open-hearth | Acid open-hearth | Acid open-hearth | Basic electric | Basic electric |

the determinations. The time-yield values for carbon, carbon–molybdenum and molybdenum–vanadium steels refer to material containing about 0·15% of carbon ; the carbon–molybdenum and molybdenum–vanadium steels having a carbon content of 0·25%, *i.e.*, comparable with that of the forging steels, would be expected to have a somewhat lower time yield, say 10–15% less than the values plotted.

Table V gives creep data obtained on test-pieces taken from various positions in certain forgings ; these were of a similar size to those referred to in Tables I to IV, some of acid-open-hearth steel and some of electric-furnace steel. The tests were carried out at 454° C. (850° F.) and 15·7 tons/sq. in., and the total strain was measured in 500 hr.

Considering the 3%-chromium–molybdenum steel first, there are no marked directional effects and no significant differences in the creep rates between open-hearth and electric steel. The average creep rate at 500 hr. is about $3 \times 10^{-6}$ in./in./hr., and a representative mean value for the extension is 0·25%, say 0·5% in 1000 hr. At a similar temperature the stress necessary to produce 0·5% extension in 1000 hr. in carbon steel varies from 5·7 to 9·3 tons.

In the case of the nickel–chromium–molybdenum steel the average creep rate at 500 hr. is $5 \times 10^{-7}$ in./in./hr., the total extension is substantially lower than for the chromium–molybdenum steel, *i.e.*, less than 0·1%, and a representative value of 0·1% in 1000 hr. may be taken. Here the value of 15·7 tons/sq. in. is to be compared with values ranging from 3·9 to 7·4 tons/sq. in. for carbon steel for a similar rate of extension. These results, then, confirm the marked superiority of both these steels over plain carbon steel for service at 450° C., and show that even in large forgings the variations in creep properties from point to point and from cast to cast are not excessive.

Table VI lists data obtained in tests at 500° C.

TABLE VI—*Results of Creep Tests for 2000 hr. at 500° C.*

| Material | Heat Treatment | Deformation, % | Stress, tons/sq. in. |
|---|---|---|---|
| 3%-Cr–Mo–V (bar) | 4 hr. at 1100° C., 16 hr. at 800° C., furnace cooled. Tempered 6 hr. at 650° C. Air cooled | 0·20 | 10 |
| Ni–Cr–Mo Rotor (No. 3, Table V) | Air-hardened and tempered. 4 hr. at 1100° C., 16 hr. at 800° C., furnace cooled. Tempered 6 hr. at 650° C. Air cooled | 0·18<br>0·10 | 10<br>10 |
| 3%-Cr–Mo Rotor (No. 1, Table V) | Oil hardened and tempered. 4 hr. at 1100° C., 16 hr. at 800° C., furnace cooled. Tempered 6 hr. at 650° C. Air cooled | 1·1<br>0·30 | 10<br>10 |
| C–Mo (bar) | Air cooled from 975° C. Tempered | 0·2 | 11[4] |
| Mo–V (bar) | Air cooled from 1000° C. Tempered | 0·2 | 14[4] |

asting up to 2000 hr. A number of additional steels are included for comparison purposes.

In the normal air-hardened and tempered condition of heat-treatment the nickel–chromium–molybdenum steel is practically identical in performance with carbon–molybdenum steel, but inferior to molybdenum–vanadium steel. Again, the 3%-chromium–molybdenum steel is inferior in creep resistance to the nickel–chromium–molybdenum steel.

The creep properties of the nickel–chromium–molybdenum and chromium–molybdenum steels are a function of the heat treatment given to the steels ; in the furnace-cooled condition the results are inferior to those for the hardened and tempered condition, and a noticeable improvement in creep resistance can be brought about by high temperature treatments. The treatments at 1100° C., 800° C., and 650° C., referred to in Table VI, were given to the alloy steels in test-piece size. It purports to simulate the treatment received by steel at the *centre* of a large forging of approximately 30 in. in diameter, when the forging is heated to 1100° C. in the hardening operation, cooled to 800° C., held until uniform, and then air hardened. The improvement in creep resistance brought about by such a treatment, whilst noteworthy, still leaves the alloy steels inferior in creep properties to those obtained from molybdenum–vanadium steel in bar form at 500° C.

These results on large forgings are in general agreement with creep determinations on bar, for example, chromium additions greater than about 1%, whilst admirable from the hardenability standpoint, lead to deterioration in creep. For the higher range of temperatures, 500°–550° C., a molybdenum–vanadium steel in the hardened and tempered condition gives a satisfactory combination of room-temperature mechanical properties and creep properties in ruling sections up to about 6 in. For the larger sizes of forgings, where uniformity is desired in room-temperature mechanical properties throughout the mass, steels of the chromium–molybdenum–vanadium or nickel–molybdenum–vanadium types are superior to the molybdenum–vanadium steel, but confirmatory data as to the creep properties on such large forgings are not yet available.

(c) *Variation in Mechanical Properties with Time*

Hatfield was particularly interested in the variations in mechanical properties which take place in alloy steels on prolonged exposure in the temperature range 400°–500° C. Three furnaces were specially constructed for operation at 400° C., 450° C., and 500° C. over long periods, and special test-pieces of 8 in. square section by 6 in. long were prepared from ingots normally used for the production of rotor forgings. These

TABLE VII (*a*)—*Results of Room-Temperature and High-Temperature Tests on Carbon Steel, after Exposure at 400°, 450°, and 500° C.*

| Duration of Heating | Exposure Temperature, °C. | Room Temperature Tests | | | | | High Temperature Tests | | | | | | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 0·50% Proof Stress, tons/sq. in. | Maximum Stress, tons/sq. in. | Elongation, % | Reduction of Area, % | Izod, ft. lb. | Testing Temperature, °C. | Proof Stress, tons/sq. in. 0·05% | 0·10% | 0·20% | 0·50% | Maximum Stress, tons/sq. in. | Elongation, % | Reduction of Area, % | Impact, ft. lb. | |
| Nil | 400 | 12·9 | 29·4 | 33 | 45 | 73, 40, 22 | 400 | 9·0 | 9·95 | 11·35 | 13·65 | 30·06 | 42 | 67 | 44, 44 | Ingot weight : 36 tons. Size of ingot : 51–57 in. octagonal. Composition, % : C, 0·22 ; S, 0·16 ; Mn, 0·63 ; S, 0·028 ; P, 0·035 ; Ni, 0·17; Cr, tr. Heat-treatment : Normalized at 880° C. |
| 6 months | | 14·8 | 29·9 | 35·5 | 59 | 33, 38, 45 | | ... | ... | ... | ... | ... | ... | ... | ... | |
| 2 years | | 14·4 | 29·4 | 36·5 | 57 | 18, 20, 23 | | 8·9 | 10·1 | 11·4 | 13·2 | 29·5 | 39 | 65 | 51, 50 | |
| Nil | 450 | 12·9 | 29·4 | 33 | 45 | 73, 40, 22 | 450 | 8·85 | 10 | 11·2 | 13·45 | 25·7 | 37 | 61 | 39, 39 | |
| 6 months | | 14·2 | 29·5 | 35 | 58 | 25, 35, 36 | | ... | ... | ... | ... | ... | ... | ... | ... | |
| 2 years | | 16·0 | 28·6 | 36 | 57 | 16, 20, 21 | | 9·0 | 10·9 | 12·2 | 14·5 | 25·4 | 36 | 64 | 49, 55 | |
| Nil | 500 | 12·9 | 29·4 | 33 | 45 | 73, 40, 22 | 500 | 7·4 | 8·9 | 10·3 | 12·3 | 22·1 | 37·5 | 68 | 31, 35 | |
| 6 months | | 13·6 | 28·1 | 37·5 | 60 | 32, 37 | | ... | ... | ... | ... | ... | ... | ... | ... | |
| 2 years | | 13·8 | 29·2 | 36·5 | 59 | 42, 35, 49 | | 8·4 | 9·0 | 10·6 | 12·7 | 23·0 | 36 | 67 | 56, 56 | |

TABLE VII (*b*)—*Results of Room-Temperature and High-Temperature Test on Carbon–Molybdenum Steel after Exposure at 400°, 450°, and 500° C.*

| Room Temperature Tests | | | | | | | High Temperature Tests | | | | | | | | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Duration of Heating | Exposure Temperature, ° C. | 0·50% Proof Stress, tons/sq.in. | Maximum Stress, tons/sq.in. | Elongation, % | Reduction of Area, % | Izod, ft. lb. | Testing Temperature, ° C. | Proof Stress, tons/sq. in. 0·05% | 0·10% | 0·20% | 0·50% | Maximum Stress, tons/sq.in. | Elongation, % | Reduction of Area, % | Impact, ft. lb. | |
| Nil | 400 | 26·4 | 41·5 | 22 | 48·5 | 16, 19, 16 | 400 | 21·6 | 24·4 | 27·45 | 31·25 | 42·9 | 23·5 | 50 | 35, 37 | Ingot weight: 10 tons. Size of ingot: 28–31 in. octagonal. Composition, %: C, 0·28; Si, 0·31; Mn, 0·65; S, 0·025; P, 0·030; Ni, 0·17; Mo, 0·67. Heat-treatment: Normalized at 870° C., reheated at 630° C. |
| 6 months | | 22·0 | 37·5 | 27 | 49·5 | 27, 26, 29 | | ... | ... | ... | ... | ... | ... | ... | ... | |
| 2 years | | 20·4 | 36·8 | 27 | 47 | 16, 10, 13 | | 12·2 | 14·45 | 17·35 | 21·35 | 35·8 | 24 | 43 | 50, 57 | |
| Nil | 450 | 26·4 | 41·5 | 22 | 48·5 | 16, 19, 16 | 450 | 10·5 | 12·9 | 15·85 | 19·7 | 34·2 | 24 | 50 | 28, 27 | |
| 6 months | | 21·6 | 37·2 | 27 | 48·5 | 15, 16, 23 | | ... | ... | ... | ... | ... | ... | ... | ... | |
| 2 years | | 22·4 | 37·8 | 26 | 47 | 15, 11, 21 | | 11·6 | 14·0 | 16·7 | 20·4 | 32·5 | 25·5 | 47 | 35, 32 | |
| Nil | 500 | 26·4 | 41·5 | 22 | 48·5 | 16, 19, 16 | 500 | 13·5 | 16·0 | 18·7 | 22·15 | 33·6 | 24 | 50 | 26, 24 | |
| 6 months | | 25·8 | 39·1 | 25 | 49 | 7, 8, 8 | | ... | ... | ... | ... | ... | ... | ... | ... | |
| 2 years | | 24·1 | 37·6 | 25 | 46·5 | 11, 10, 7 | | 12·6 | 14·4 | 16·3 | 18·7 | 26·6 | 29 | 65·5 | 43, 43 | |

TABLE VII (*c*)—*Results of Room-Temperature and High-Temperature Test on Nickel–Chromium–Molybdenum Steel after Exposure at 400°, 450°, and 500° C.*

| Room Temperature Tests | | | | | | | High Temperature Tests | | | | | | | | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Duration of Heating | Exposure Temperature, ° C. | 0·50% Proof Stress, tons/sq.in. | Maximum Stress, tons/sq.in. | Elongation, % | Reduction of Area, % | Izod, ft. lb. | Testing Temperature, ° C. | Proof Stress, tons/sq. in. 0·05% | 0·10% | 0·20% | 0·50% | Maximum Stress, tons/sq.in. | Elongation, % | Reduction of Area, % | Impact, ft. lb. | |
| Nil | 400 | 37·7 | 47·9 | 23·5 | 56·5 | 46, 57, 42 | 400 | 29·4 | 31·1 | 33·0 | 34·8 | 45·1 | 25 | 55 | 59, 55 | Ingot weight: 67 tons. Size of ingot: 69–73 in. octagonal. Composition, %: C, 0·28; Si, 0·19; Mn, 0·48; S, 0·025; P, 0·028; Ni, 2·49; Cr, 0·53; Mo, 0·47. Heat-treatment: Air hardened at 850° C., tempered at 640° C. |
| 6 months | | 39·0 | 48·4 | 25 | 58·5 | 19, 21, 15 | | ... | ... | ... | ... | ... | ... | ... | ... | |
| 1½ years | | 38·0 | 48·2 | 24 | 60·5 | 16, 14, 15 | | 30·2 | 31·8 | 33·2 | 35·25 | 43·1 | 20 | 58·5 | 96, 91 | |
| Nil | 450 | 37·7 | 47·9 | 23·5 | 56·5 | 46, 57, 42 | 450 | 29·2 | 30·4 | 31·9 | 34·2 | 40·1 | 25 | 59 | ... | |
| 6 months | | 38·0 | 48·4 | 25 | 59 | 10, 15, 12 | | ... | ... | ... | ... | ... | ... | ... | ... | |
| 1½ years | | 38·4 | 48·2 | 24 | 58·5 | 8, 8, 7 | | 27·8 | 29·1 | 30·2 | 32·0 | 38·8 | 22·5 | 58·5 | 86, 82 | |
| Nil | 500 | 37·7 | 47·9 | 23·5 | 56·5 | 46, 57, 42 | 500 | 25·9 | 27·6 | 29·0 | 31·1 | 35·7 | 26 | 65·5 | 45, 33 | |
| 6 months | | 37·2 | 47·5 | 23·5 | 60 | 20, 20, 20 | | ... | ... | ... | ... | ... | ... | ... | ... | |
| 1½ years | | 35·6 | 45·6 | 25 | 59·5 | 21, 12, 17 | | 24·3 | 25·5 | 26·6 | 27·6 | 30·4 | 28 | 73 | 75, 75 | |

TABLE VII (*d*)—*Results of Room-Temperature and High-Temperature Tests on Chromium–Molybdenum Steel after Exposure at 400°, 450°, and 500° C.*

| Duration of Heating | Exposure Temperature, ° C. | Room Temperature Tests: 0·50% Proof Stress, tons/sq. in. | Maximum Stress, tons/sq. in. | Elongation, % | Reduction of Area, % | Izod, ft. lb. | Testing Temperature, ° C. | High Temperature Tests: Proof Stress, tons/sq. in. 0·05% | 0·10% | 0·20% | 0·50% | Maximum Stress, tons/sq. in. | Elongation, % | Reduction of Area, % | Impact, ft. lb. | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Nil | 400 | 36·4 | 48·8 | 21 | 52·5 | 66, 59, 55 | 400 | 27·6 | 29·4 | 31·9 | 33·1 | 43·1 | 24 | 43 | 92, 104 | Ingot weight: 72 tons. Size of ingot: 60–66 in. octagonal. Composition, %: C, 0·25; Si, 0·24; Mn, 0·60; S, 0·025; P, 0·028; Ni, 0·93; Cr, 3·27; Mo, 0·47. Heat-treatment: Air hardened at 900° C., tempered at 720° C. |
| 6 months | | 29·5 | 43·4 | 26 | 58 | 40, 36, 45 | | 25·0 | 26·1 | 27·4 | 29·2 | 40·4 | 20 | 55 | 112, 102 | |
| 1½ years | | 33·1 | 46·4 | 23·5 | 61·5 | 17, 23, 28 | | | | | | | | | | |
| Nil | 450 | 36·4 | 48·8 | 21 | 52·5 | 66, 59, 55 | 450 | 25·8 | 27·3 | 28·8 | 31·2 | 40·3 | 29 | 63 | 98, 110 | |
| 6 months | | 35·7 | 49·0 | 24·5 | 61 | 20, 20, 20 | | ... | ... | ... | ... | ... | ... | ... | ... | |
| 1½ years | | 32·7 | 45·6 | 23 | 60 | 27, 24, 26 | | 25·6 | 27·2 | 28·4 | 30·8 | 37·6 | 20 | 55 | 107, 100 | |
| Nil | 500 | 36·4 | 48·8 | 21 | 52·5 | 66, 59, 55 | 500 | 24·0 | 26·0 | 27·6 | 29·6 | 35·8 | 31 | 70·5 | 98, 90 | |
| 6 months | | 36·6 | 50·7 | 19·5 | 44·5 | 12, 15, 16 | | ... | ... | ... | ... | ... | ... | ... | ... | |
| 1½ years | | 33·4 | 41·0 | 26·5 | 61 | 14, 10, 10 | | 23·0 | 24·9 | 26·6 | 28·5 | 35·6 | 21·5 | 55 | 102, 100 | |

were given the normal heat-treatment prior to exposure for periods up to two years at elevated temperatures.

A number of different steels were tested, the particulars relating to the steels of the type referred to in sections (*a*) and (*b*) are tabulated in Tables VII (*a*, *b*, *c*, and *d*). All were of acid-open-hearth manufacture.

Mechanical-test results are recorded as measured at room temperature, after exposure for periods up to two years at 400° C., 450° C., and 500° C. In addition, the mechanical properties are also recorded at the temperature of exposure. The results may be summarized as follows.

There is a slight increase in proof stress at room temperature after exposure in the case of the carbon steel and the nickel–chromium–molybdenum steel, and a slight fall in proof stress in the 3%-chromium–molybdenum and carbon–molybdenum steels. The changes in elongation and reduction-of-area are very small for all of the steels, with a slight improvement for the chromium–molybdenum steel.

Some of the Izod values show considerable change with time: the carbon–molybdenum steel which has a relatively low Izod to begin with changes only slightly; the Izod values of the three other steels deteriorate with time at 400° C. and 450° C., the lowest values being recorded for the nickel–chromium–molybdenum steel at 450° C. At 500° C. there is a drop after six months' exposure, but thereafter no further drop occurs, and in certain cases further exposure appears to lead to some improvement.

The mechanical tests carried out at the exposure temperatures indicate that at elevated temperatures the proof stress of the alloy steels is much superior to that of the carbon and carbon–molybdenum steels; the ductility of all the materials is satisfactorily high, and the Izod values are substantially higher than those obtained at room temperatures before exposure. Exposure in the temperature range 400°–500° C. gives rise to an increase in Izod value as measured at the temperature of exposure for all steels.

These results indicate that the physical properties of the alloy steels in the form of large forgings do not undergo any rapid variation with exposure to working temperatures in the 400°–500° C. region. On cooling to room temperature some falling off in Izod value, but not in ductility, is to be expected. This drop in Izod is restored on reheating to the working temperature.

### (2) STEELS OF THE R. EX 78 TYPE

It will be evident from Figs. 1 and 2 that the creep strength of the ferritic steels falls off very rapidly in the temperature range 500°–600° C. In addition the rate of oxidation increases rapidly from 600° C. upwards. Thus, ferritic steels are usually limited to short-term applications in the range 550°–600° C. unless very low stresses can be used. For higher temperatures it is customary to use materials containing chromium in excess of 12%, and in this class the austenitic steels of the 18/8 type have been found to combine good

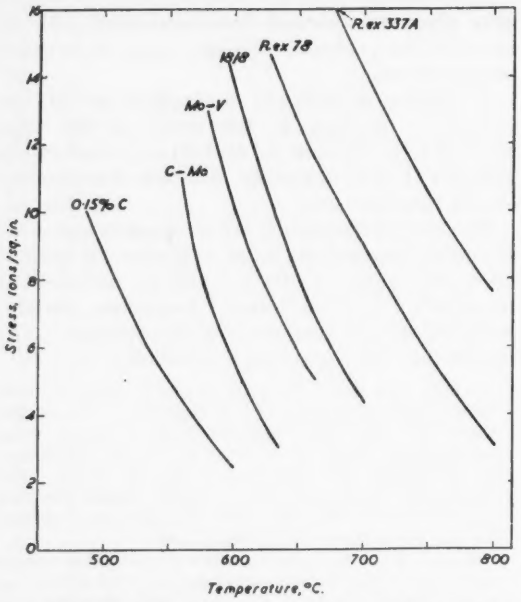


FIG. 3—Stress/temperature curves to produce rupture in 1000 hr. for a variety of materials (in the triple-treated condition)

oxidation resistance with good creep properties. Figure 3 gives the value of stress to produce rupture in 1000 hr. for a variety of materials, as a function of temperature, and it will be seen that the 18/8 type of material represents a considerable improvement on molybdenum–vanadium steel.

The 18/8 steel may be taken as typical of austenitic material in 1936. Subsequent to that date a group of new steels—austenitic steels with high creep resistance — have appeared; the enhanced creep properties being obtained after a high-temperature solution treatment, followed by precipitation hardening at a somewhat lower temperature.

The forerunner of this class of steel was R. ex 78, developed by Hatfield from 1936 onwards, and ultimately used for blading and discs in the early Whittle engines. It is of interest to consider some of the properties of R. ex 78 steel and its behaviour under heat treatment :

### (a) *R. ex 78 Steel*

The chemical composition of R. ex 78 steel is :

| C, % | Si, % | Mn, % | Ni, % | Cr, % |
|---|---|---|---|---|
| 0·12 max. | 1·0 max. | 1·0 max. | 17–18·5 | 13–14·5 |

| Cu, % | Mo, % | Va, % | Ti, % |
|---|---|---|---|
| 3·5–4·5 | 3·5–4·5 | 0·25 max. | 0·5–1·0 |

This complex steel was originally developed without titanium, as a corrosion-resisting steel, and is particularly resistant to sulphuric acid. However, it was found to be susceptible to intercrystalline corrosion when submitted to the usual intercrystalline-corrosion test. For this reason, titanium was added, which cured the trouble, and then, as is customary in the Laboratories, its normal mechanical properties and creep properties were ascertained.

The mechanical properties of the $1\frac{1}{8}$ in. bar are given in Table VIII for the three conditions of heat-treatment in use at that time.

(i) As hot rolled.
(ii) As air cooled from 1050° C.
(iii) As air cooled from 1050° C., 3 hr. at 800° C. and air cooled, and 48 hr. at 600° C.

Conditions (ii) and (iii) give very similar properties at room temperature, although in creep there is a considerable difference. Figure 4 gives the time-yield figures for bar in the air-cooled from 1050° C. condition, and after the so-called triple treatment, and Fig. 3 gives rupture values for the triple-treated condition.

It will be seen that the creep strength at 600° C. and higher is quite exceptional when compared with either the ferritic steels or other austenitic steels available at the time. Thus, at a stress of 6 tons, R. ex 78 steel shows roughly the same improvement over molybdenum–vanadium steel that molybdenum–vanadium steel has over plain carbon steel.

TABLE VIII—*Physical Properties of R. ex 78 in $1\frac{1}{8}$-in. Dia. Form*

| Condition | Physical Properties | | | | | | |
|---|---|---|---|---|---|---|---|
| | Proof Stress, tons/sq. in. | | | Maximum Stress, tons/sq. in. | Elongation, % | Reduction of Area, % | Izod, ft. lb. |
| | 0·05% | 0·10% | 0·50% | | | | |
| As rolled ... ... ... ... ... | 25·9 | 27·6 | 30·3 | 42·0 | 38 | 62·5 | 95, 98, 95 |
| Air cooled from 1050° C. ... ... ... | 18·3 | 19·7 | 22·2 | 38·2 | 49 | 64·5 | 85, 98, 105 |
| Air cooled from 1050° C.; reheated to 800° C., held for 3 hr. and air cooled. Reheated to 600° C., held for 48 hr. and air cooled ... ... ... ... | 19·2 | 20·2 | 21·8 | 42·0 | 39 | 57 | 85, 81, 84 |

Hatfield appreciated the importance of these results immediately, namely, that the creep resistance of R. ex 78 steel was quite exceptional, and that its behaviour was intimately connected with the prior heat-treatment given to the material. Comprehensive series of heat-treatment experiments, using solution treatments up to 1250° C., were put in hand. These confirmed that R. ex 78 was a precipitation-hardening alloy and that the creep properties were controlled by the degree of precipitation present in the material. The triple treatment was finally standardized as giving the best compromise between room-temperature and high-temperature properties. As a matter of interest, he also carried out accurate measurements of the variations in length of unstressed specimens when exposed at 600° C., and showed that contractions of up to 0·10% could occur, depending on the prior treatment.

At the present time, with a wealth of literature on the precipitation-hardening effects in complex austenitic steels, this experimental work of Hatfield's is readily interpreted. The spade-work on the heat-treatment of R. ex 78 was carried out in 1936/37—ten years ago—when little was known of the mechanism of either creep or precipitation. The progress made with the practical problems in R. ex 78 reflects great credit on Hatfield and his collaborators.

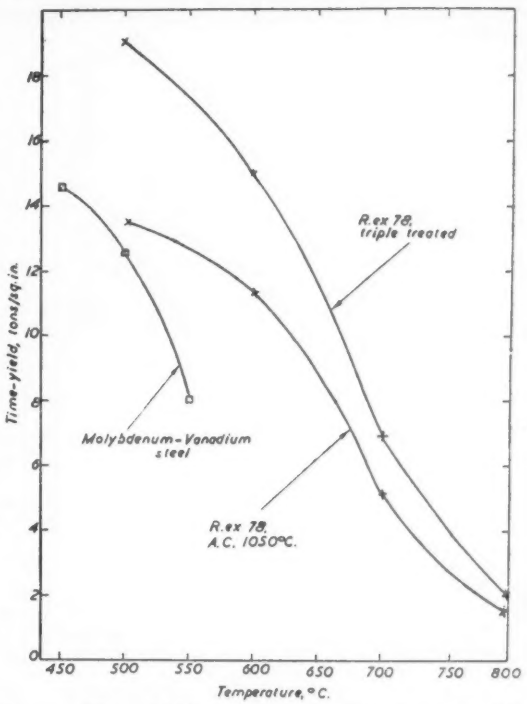


FIG. 4—Time-yield/temperature curves for materials air-cooled from 1050° C., after triple treatment

### (b) *Modifications of R. ex 78 steel*

One immediate reaction to an examination of the chemical composition of R. ex 78 might be that it is very complicated, and the question might well be put, "Are all the various elements necessary?" To answer such a question, and in addition, to decide which of the great variety of possible heat-treatments gives the optimum properties, both for long-term and short-period service, is a very formidable task indeed.

The only sound method available at the present time is to vary the concentration of each element systematically keeping the remainder fixed, and to then measure the usual mechanical properties and creep properties over the likely service range of temperature. These tests usually give a clear indication of the critical ranges of each element for a given 'basic' composition. Then, by a successive series of approximations, a final balanced composition is achieved. In this way the influence of carbon, copper, molybdenum, and subsequently cobalt, were studied in some detail, preliminary experiments having indicated that variations in nickel and chromium of the order of − 1% to + 3% were not critical.

As a result of this investigation slight modifications in composition have been made to R. ex 78; the carbon content has been increased to 0·2%, and 7% of cobalt added. This alloy (R. ex 337A), when solution treated at 1230° C. and aged at 700°–750° C., has superior creep properties to

TABLE IX (*a*)—*Physical Properties of R. ex 337A in 1⅛-in. Dia. Bar Form*

| Temperature of Test, °C. | Proof Stress, tons/sq. in. | | | | Maximum Stress, tons/sq. in. | Elongation, % | Reduction of Area, % | Izod, ft. lb. | Young's Modulus | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|
| | 0·05% | 0·10% | 0·20% | 0·50% | | | | | | |
| Room | 20·0 | 22·4 | 24·1 | 26·6 | 44·4 | 37½ | 43 | 81, 87, 90 | 12600 | Water quenched after 4 hr. at 1230° C., 48 hr. at 700° C. Composition, %: C, 0·23; Si, 0·91; Mn, 0·74; Ni, 17·85; Cr, 14·66; Mo, 3·75; Cu, 3·55; Co, 7·20; Ti, 0·82. |
| 600 | 17·4 | 18·7 | 19·9 | 21·6 | 31·8 | 21 | 24½ | ... | 9800 | |
| 700 | 14·5 | 16·1 | 17·6 | 19·4 | 24·4 | 18½ | 22 | ... | ... | |
| 800 | 11·0 | 12·5 | 13·6 | 14·9 | 17·15 | 20½ | 24½ | ... | 8800 | |

TABLE IX (*b*)—*Effect of Exposure of R. ex 337A at 600° and 650° C.*

| Exposure Temperature, ° C. | Time at Temperature | Proof Stress, tons/sq. in. | | | Maximum Stress, tons/sq. in. | Elongation, % | Reduction of Area, % | Izod, ft. lb. |
|---|---|---|---|---|---|---|---|---|
| | | 0·05% | 0·10% | 0·50% | | | | |
| 600 | Nil | 17·1 | 19·5 | 24·2 | 43·5 | 39½ | 44½ | 59 |
| | 2 days | 16·85 | 19·8 | 25·3 | 44·3 | 40 | 41 | 56 |
| | 2 weeks | 16·75 | 19·1 | 24·2 | 43·8 | 37½ | 39 | 48 |
| | 3 months | 17·1 | 20·0 | 25·55 | 43·9 | 36 | 39 | 40 |
| 650 | Nil | 17·1 | 19·5 | 24·2 | 43·5 | 39½ | 44½ | 58 |
| | 2 days | 24·1 | 26·6 | 30·7 | 44·9 | 35 | 41 | 44 |
| | 2 weeks | 25·5 | 27·7 | 31·5 | 45·6 | 37 | 39 | 40 |
| | 3 months | 24·4 | 27·4 | 33·4 | 52·4 | 28 | 25½ | 30 |

TABLE IX (*c*)—*Physical Properties of R. ex 78 in 1⅛-in. Dia. Bar Form in the Triple-Treated Condition*

| Temperature of Test, ° C. | Proof Stress, tons/sq. in. | | | | Maximum Stress, tons/sq. in. | Elongation, % | Reduction of Area, % | Izod, ft. lb. | Young's Modulus | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|
| | 0·05% | 0·10% | 0·20% | 0·50% | | | | | | |
| Room | 19·2 | 20·2 | 20·9 | 21·8 | 42·0 | 39 | 57 | 85, 81, 84 | 12300 | Composition, % : C, 0·08 ; Si, 0·58 ; Mn, 0·40 ; Ni, 18·24 ; Cr, 14·20 ; Mo, 3·63 ; Cu, 4·24 ; Ti, 0·60. |
| 600 | 16·6 | 17·6 | 18·6 | 20·1 | 32·55 | 14½ | 17 | ... | 9500 | |
| 700 | ... | ... | ... | ... | 22·25 | 16 | 17 | ... | ... | |
| 800 | ... | ... | ... | ... | 16·0 | 22 | 25 | ... | 8500 | |

TABLE IX (*d*)—*Effect of Exposure of R. ex 78 at 600° and 700° C.*

| Exposure Temperature, ° C. | Time at Temperature | Yield Point, tons/sq. in. | Maximum Stress, tons/sq. in. | Elongation, % | Reduction of Area, % | Izod, ft. lb. | Remarks |
|---|---|---|---|---|---|---|---|
| | Nil | 17·25 | 37·0 | 47·0 | 68·0 | 99, 102, 104 | Heat-treatment : air cooled at 1050° C. |
| 600 | 48 hr. | 21·6 | 40·2 | 42·0 | 66·0 | 98, 79, 106 | |
| 700 | 48 hr. | 24·0 | 39·8 | 40·0 | 62·0 | 91, 83, 84 | |

TABLE IX (*e*)—*Results of Physical Tests on F.C.B. 1⅛-in. Dia. Bar in the Air-Cooled from 1050° C. Condition*

| Temperature of Test, ° C. | Proof Stress, tons/sq. in. | | | | Maximum Stress, tons/sq. in. | Elongation, % | Reduction of Area, % | Izod, ft. lb. | Young's Modulus | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|
| | 0·05% | 0·10% | 0·20% | 0·50% | | | | | | |
| Room | 11·2 | 13·3 | 15·2 | 17·2 | 40·8 | 58½ | 65½ | 103, 98, 103 | 13,100 | Composition, % : C, 0·11 ; Si, 0·50 ; Mn, 0·41 ; Ni, 9·5 ; Cr, 17·84 ; Cb, 1·22. |
| 600 | 8·55 | 0·05 | 9·65 | 10·55 | 24·55 | 40 | 62 | ... | 9700 | |
| 700 | ... | ... | ... | ... | 19·25 | 46½ | 70 | ... | 9130 | |
| 800 | ... | ... | ... | ... | ... | ... | ... | ... | ... | |

TABLE IX (*f*)—*Tensile Properties of F.C.B. Creep Test-Piece, after 6615 hr. at 650° C. and a Stress of 4 tons/sq. in.*

| Creep Strain, % | Yield Point, tons/sq. in. | Maximum Stress, tons/sq. in. | Elongation on $4\sqrt{A}$, % | Elongation on 4in., % | Reduction of Area, % |
|---|---|---|---|---|---|
| 1·05 | 21·6 | 43·2 | 50 | 38 | 51½ |

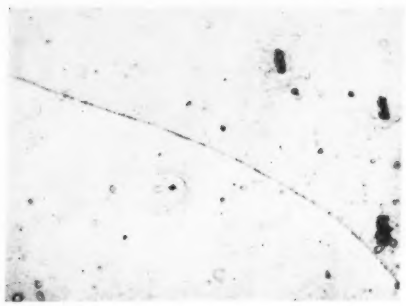

FIG. 5—As solution-treated. × 2000

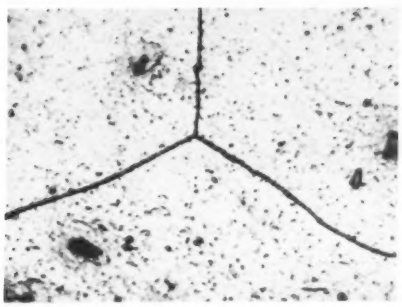

FIG. 6—Aged for 4 hr. × 2000

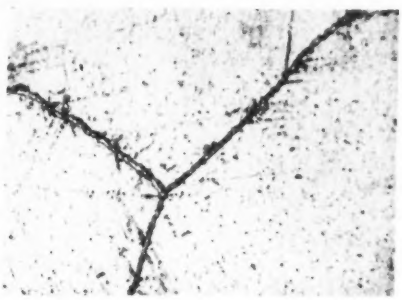

FIG. 7—Aged for 48 hr. × 2000

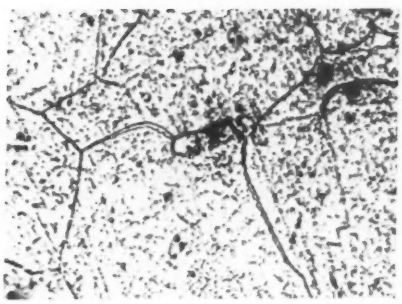

FIG. 8—Aged for 540 hr. × 2000

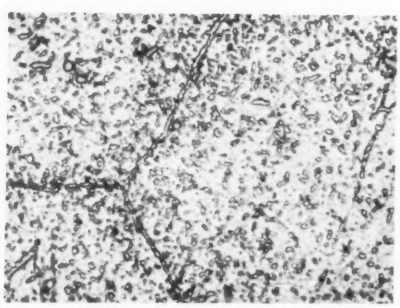

FIG. 9—Aged for 2000 hr. × 2000

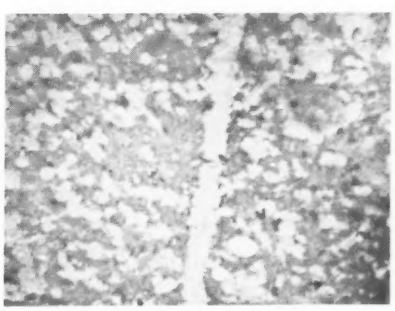

FIG. 10—Aged for 2000 hr. × 6000
(by electron microscope)

FIGS. 5–10—Effect of time of exposure at 700° C. on steel R. ex 337A, after solution heat-treatment for 4 hr. at 1250° C. and water-quench (reduced to five-eighths linear in reproduction)

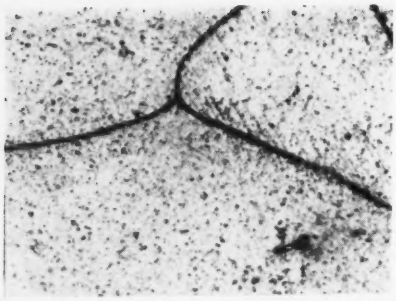

FIG. 11—0·1% of carbon. × 2000

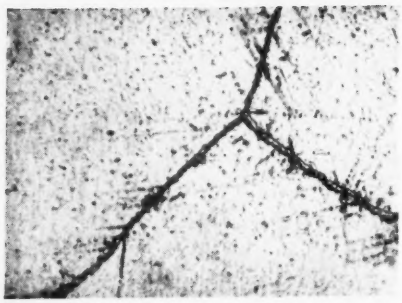

FIG. 12—0·2% of carbon. × 2000

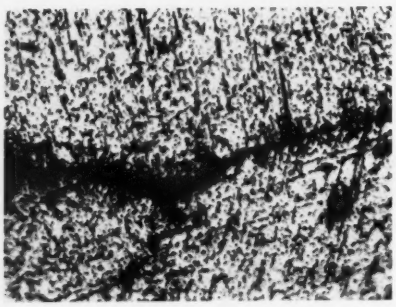

FIG. 13—0·4% of carbon. ×2000

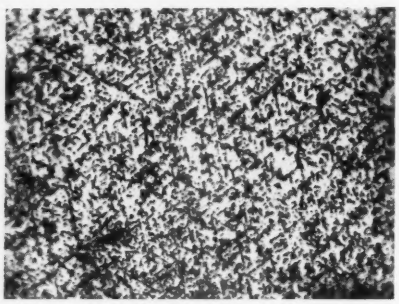

FIG. 14—As in Fig. 13, but aged at 800° C. × 1500

FIGS. 11–14—Effect of varying carbon content on steel similar to R. ex 337A after ageing for 48 hr. at 700° C. All previously solution heat-treated for 4 hr. at 1250° C. and water-quenched (reduced to five-eighths linear in reproduction)

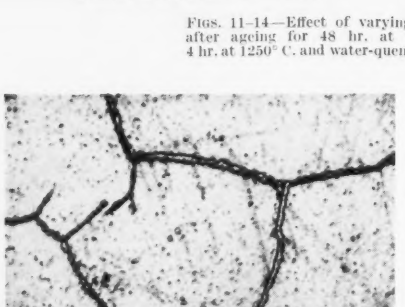

FIG. 15—No cobalt. × 2000

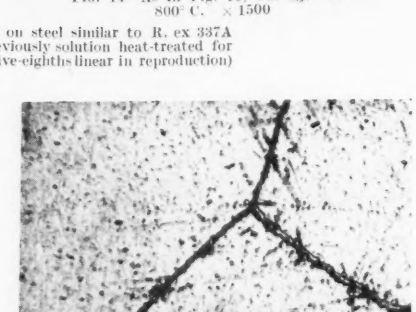

FIG. 16—7% of cobalt. × 2000

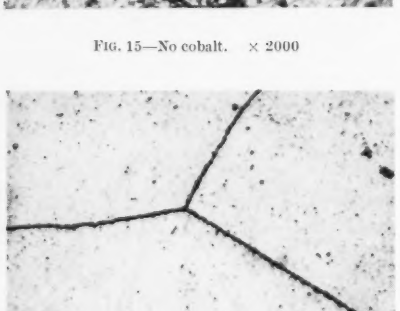

FIG. 17—12% of cobalt. ×2000

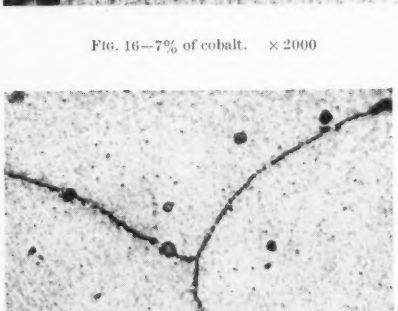

FIG. 18—17% of cobalt. × 2000

FIGS. 15–18—Effect of increasing the cobalt content on the degree of precipitation of steel R. ex 337A; after 4 hr. solutionizing at 1250° C., water-quench, and ageing for 48 hr. at 700° C. (reduced to five-eighths linear in reproduction)

TABLE IX (*g*)—*Effect of Exposure of F.C.B. at 600° and 650° C.*

| Exposure Temperature, ° | Time at Temperature | Proof Stress, tons/sq. in. | | | Maximum Stress, tons/sq. in. | Elongation, % | Reduction of Area, % | Izod, ft. lb. |
|---|---|---|---|---|---|---|---|---|
| | | 0·05% | 0·10% | 0·50% | | | | |
| 600 | Nil | 14·8 | 17·0 | 20·7 | 45 | 55 | 62 | 101 |
| | 2 days | 16·1 | 18·0 | 21·4 | 44·3 | 48 | 54 | 91 |
| | 2 weeks | 15·0 | 18·1 | 22·3 | 46·0 | 52 | 57½ | 89 |
| | 3 months | 14·25 | 17·5 | 21·65 | 43·5 | 47½ | 57½ | 106 |
| 650 | Nil | 14·8 | 17·0 | 20·7 | 45·0 | 55 | 62 | 101 |
| | 2 days | 15·8 | 17·7 | 20·85 | 44·5 | 52 | 59 | 88 |
| | 2 weeks | 15·3 | 17·6 | 21·4 | 44·3 | 50 | 54 | 76 |
| | 3 months | 11·5 | 14·1 | 18·3 | 42·0 | 54 | 60½ | 101 |

R. ex 78, *see* Fig. 3. It is perhaps useful to reflect that, although these changes are quite small, *viz.*, an increase in carbon from 0·07% to 0·2%, an addition of cobalt, and a change in heat-treatment, nevertheless the rupture strength at 800° C. in 1000 hr. has been increased from 3 tons/sq. in. to 7·5 tons/sq. in. This, I think, brings out very clearly how critically the various factors have to be balanced in order to obtain optimum properties.

The normal mechanical properties of R. ex 337A, R. ex 78, and Staybrite F.C.B. steel (an 18/11 material having creep properties intermediate between those for 18/8 and those for R. ex 78, plotted in Fig. 3) are given in Tables IX (*a–h*). The improvement in creep properties associated with R. ex 337A is also accompanied by higher proof strength, both at room temperature and at elevated temperatures. All three materials remain completely austenitic when exposed for long periods in the 600°–650° C. temperature region.

### (c) *Precipitation Phenomena in Steels of the R. ex 78 Class*

As indicated in the previous paragraph, the study of steels of this type is extremely involved and time consuming, due to the large number of variables. Consequently, it is essential to make use of research facilities other than creep equipment, in order to obtain some general physical picture of the metallurgical changes proceeding in the steels, and in particular to ascertain the special role, if any, played by each individual element in the performance of the alloy.

TABLE IX (*h*)—*Creep Stress for Indicated Strain in 1000 hr.*

Representative of bar material and small disc forgings

| | R. ex 78 | | | R. ex 337 A | | |
|---|---|---|---|---|---|---|
| Temperature, C°. | 0·2% Strain | 0·5% Strain | Strain at Fracture | 0·2% Strain | 0·5% Strain | Strain at Fracture |
| 650 | 8 | 9·5 | 12·5 | 12 | 14 | 17 |
| 700 | 5·5 | 6·5 | 9 | 9·5 | 11 | 13 |
| 750 | 3·5 | 4·5 | 5·5 | 8·0 | 8·5 | 10 |
| 800 | 2 | 2·5 | 3 | 6·5 | 7 | 7·5 |

Three main methods have been used to supplement the creep data : the microscope, electrical resistivity measurements, and examination of chemical residues by microchemical methods. Much useful information has been accumulated by these methods. Some typical results of this type of experimental work will be given.

#### *Metallographical Examination*

Figures 5–9 show the effect of exposure at 700° C. on solution-treated R. ex 337A material. Precipitation is most active at the grain boundaries in the initial stages. Such precipitation as occurs initially in the grains appears to be highly oriented and to follow the crystallographic planes in the individual grains, *see* Figs. 7–8. Subsequently, when a uniform precipitation has occurred throughout the grains, further exposure is followed by spheroidization of the precipitate, *see* Fig. 9. The precipitates are less readily attacked than the matrix by the etching reagent (10% hydrochloric acid), and are left in relief, as may be deduced from the electron microscope photograph, Fig. 10.

Figures 11–13 give a similar set of structures for steels of a similar base analysis to R. ex 337A, but containing different carbon contents. The amount of precipitate increases with increasing carbon content. Higher ageing temperatures accentuate the tendency for the precipitate to orient itself on the crystallographic planes of the matrix, *see* Fig. 14.

Figures 15–18 show the effect of increasing amounts of cobalt on the degree of precipitation after 48 hr. at 700° C. It is clear that cobalt slows up the rate of precipitation.

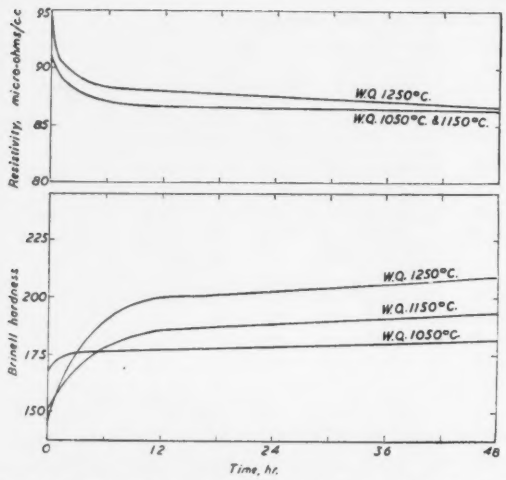


FIG. 19—The effect of time of treatment at 700° C. on hardness and resistivity of solution-treated R. ex 337A steel

*Resistivity and Hardness Determinations*

The precipitation process is accompanied by changes in hardness and electrical resistivity. As the solution-treatment temperature is increased, the amount of material taken into solution increases, and the hardening produced by precipitation at any given temperature is increased. Figure 19 shows the change in hardness and resistivity with time at 700° C. on R. ex 337A material solution-treated at different temperatures.

Figure 20 gives resistivity measurements made at room temperature on steels of the R. ex 337A type differing only in copper content, after solution treatment at 1250° C. and ageing for differing periods at 700° C. It is not clear whether the curves showing a large initial drop with a subsequent slow decrease in resistivity are to be interpreted as the result of the precipitation of two different constituents, or whether the initial part of the curve is caused by nucleation and the subsequent part by spheroidization. Both interpretations are equally plausible. One interesting fact is that the materials shown in Fig. 20 having the flat curve, indicating little or no precipitation after the first 2 hr., have relatively poor creep properties.

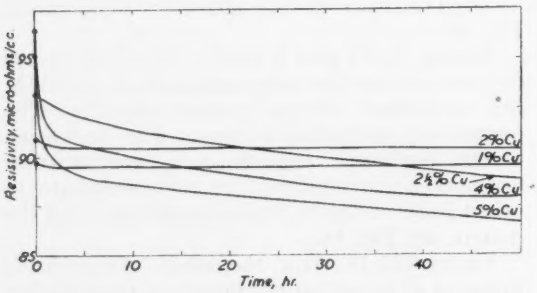


FIG. 20—The effect of time of heat-treatment at 700° C. on the resistivity, after solution heat-treatment at 1250° C.

*Microchemical Data*

In work of this type it is obviously important to determine, whenever possible, the actual phases which are precipitated. In steels as complex as R. ex 78, metallographic examination, and resistivity and hardness determination methods, whilst providing valuable ' background ' information, give no clear indication on this particular question. The creep performance cannot be directly correlated with the amount of precipitate available : thus, material characterized by Fig. 12 is superior in creep to that of Figs. 11 and 13, and moreover, it does not follow that a precipitate, apparently etching in a similar manner throughout the matrix, is in fact a single constituent. Different precipitated phases may be present, some of which may affect the creep properties adversely.

We have used the microchemical method in an endeavour to identify the precipitate.

Samples have been broken down by electrolytic means ; the steel sample being used as anode in a solution consisting of 30 g. of citric acid, 20 g. of potassium iodide, 4 c.c. of hydrochloric acid, and 60 c.c. of water. The residue was then filtered from the electrolyte, re-dissolved, and analysed by microchemical methods for molybdenum, copper, titanium, iron, chromium, and nickel, etc. In general the proportion of nickel, cobalt, and iron present in the residue is invariably small,

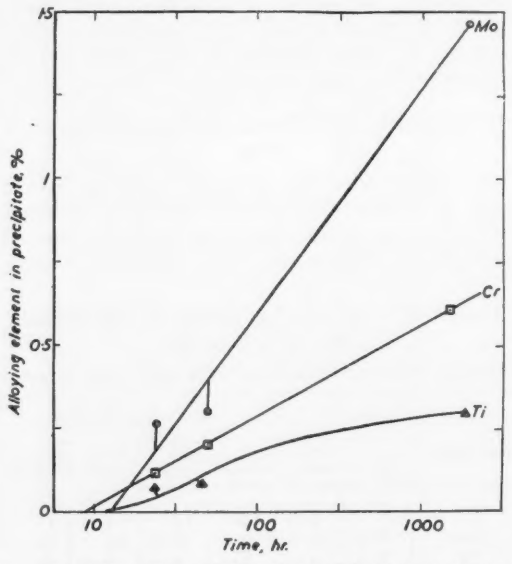


FIG. 21—The effect of the time of heat-treatment at 700° C. on the composition of the precipitate in R. ex 337A, as determined electrolytically

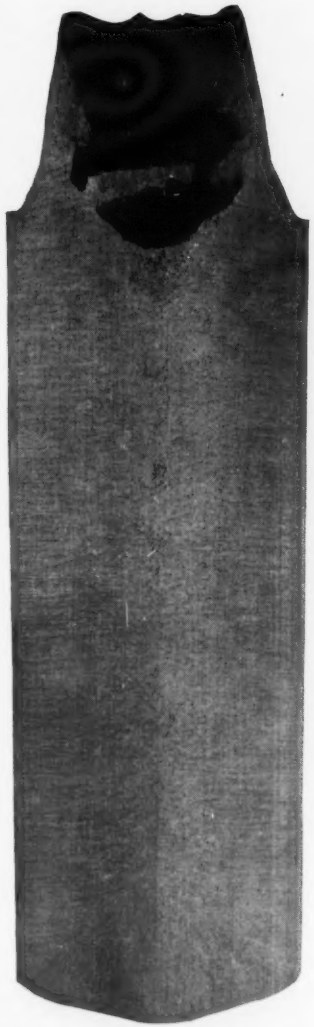

FIG. 22—Longitudinal section through a 16 × 11-in. slab ingot of 18/8

FIG. 24—9 × 8-in. chill mould

FIG. 25—9 × 6-in. chill mould

FIGS. 24–27—Longitudinal sections through ingots of R. ex 78 made in chill moulds of different taper

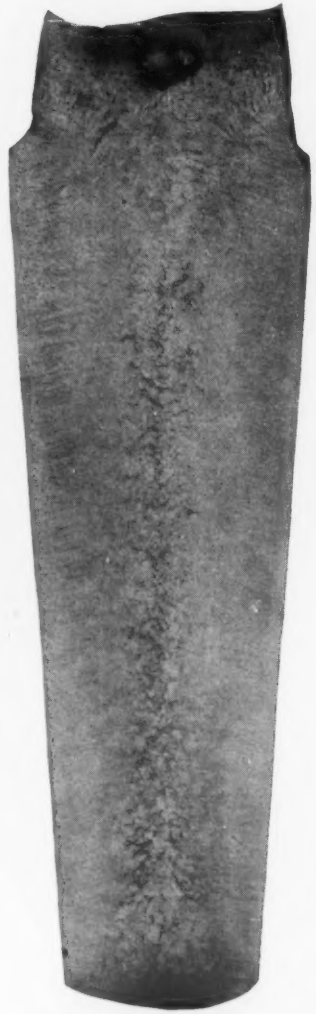

FIG. 26—13 × 8-in. chill mould

FIG. 27—11 × 9-in. chill mould with refractory bottom

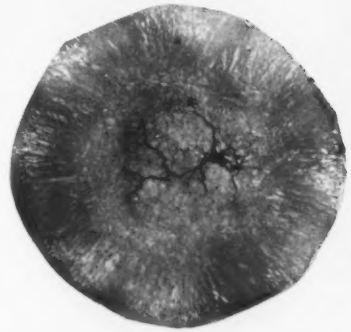

FIG. 23—Cross-section through an R. ex 78 steel ingot, showing cracking at the central zone after slight reduction by forging

Sykes
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FIG. 28—Longitudinal section through an 11 × 9-in. chill cast R. ex 78 ingot, top heated by oxy-acetylene torch during feeding

FIG. 29—Longitudinal section through 11 × 9-in. sand-cast R. ex 78 ingot

FIG. 30—Longitudinal section through 11 × 9-in. sand-cast R. ex 78 ingot with top heated by oxy-acetylene torch during feeding

FIG. 31—Longitudinal section of 11 × 9-in. R. ex 78 ingot cast in a composite mould

Refractory

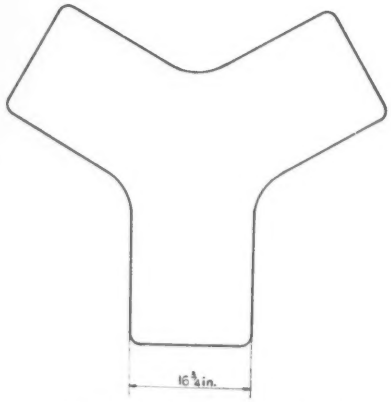


FIG. 32—Sketch of cross-section of 3-winged ingot

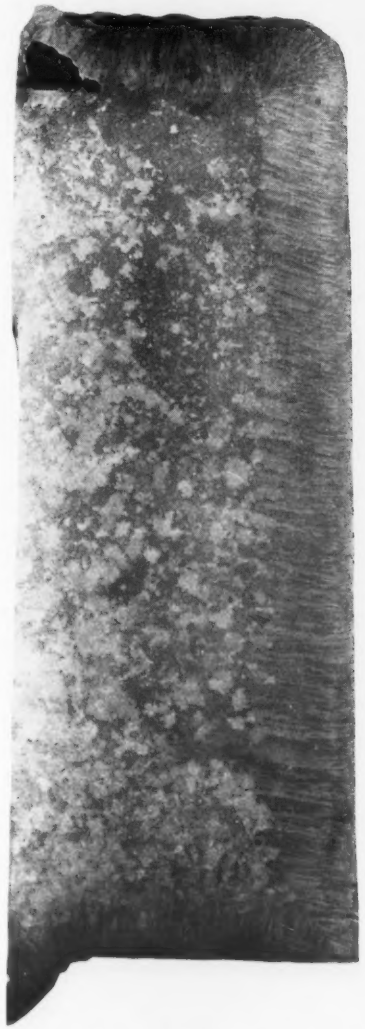

FIG. 33—Longitudinal section through one wing of 3-winged ingot

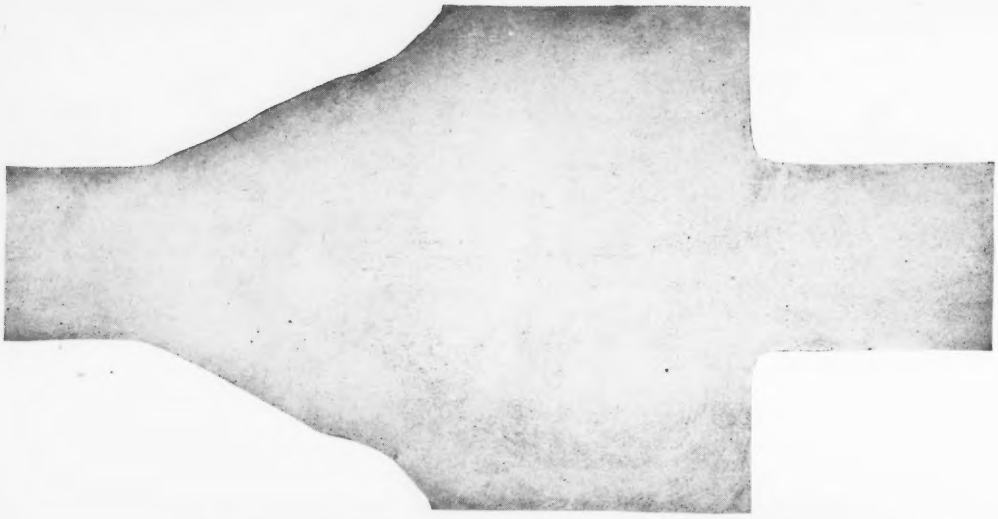

FIG. 34—Longitudinal section through F.C.B. forging produced from a 10-ton ingot

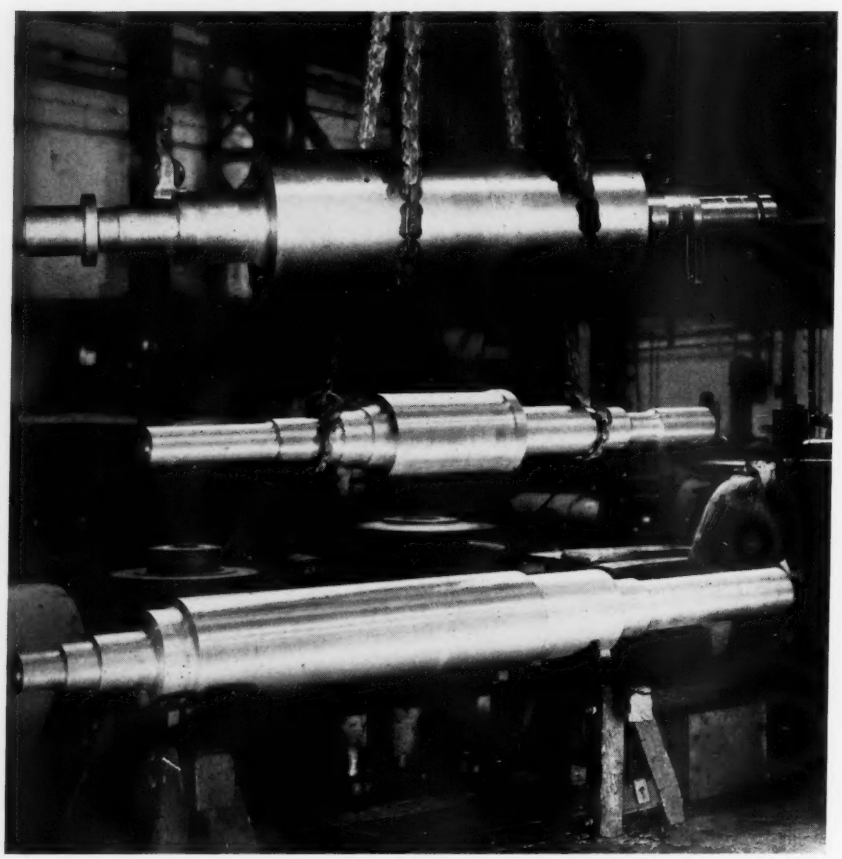

FIG. 35—Photograph of three finished rotors in F.C.B. material

*Sykes]*
*To face p. 335]*

approximately 0·2% maximum, and is considered to be the remnant of the undissolved steel. The weight of the remainder of the residue is adjusted for these amounts.

It is appreciated that this experimental method is open to criticism and subject to many technical difficulties. In this case, however, no more promising method has yet been developed, and the results obtained, if applied with reasonable judgement, do assist in the interpretation of the complex behaviour of the steels in question.

Figure 21 shows the increase in weight of different elements in the residue obtained from R. ex 337A, expressed as a percentage of the weight of steel examined, which occurs when the solution-treated material is aged at 700° C. It will be seen that up to 2000 hr. the amounts of molybdenum, chromium, and titanium appearing in the precipitate increase with time. Up to 48 hr., the absolute amounts and relative proportions of all three of these metals are such that they could be present as carbides having the following formulæ: TiC, MoC, and $Cr_4C$. Beyond this period there is insufficient carbon in the steel to cope with the metals as carbide, and it seems that an intermetallic compound which contains molybdenum is precipitated. Titanium carbide can be readily detected in the precipitates by X-ray methods.

As a further example of the type of information afforded by this method, the effect of carbon content on the constitution of the precipitate may be quoted, *see* Table X. All the steels were similar to R. ex 337A, except for variations in carbon content, the solution treatment was 4 hr. at 1250° C., and the precipitation treatment was 48 hr. at 700° C.

The increase in carbon content leads to a reduction of titanium in the precipitate, and a marked increase in chromium and molybdenum. From creep data, steels containing carbon contents as high as 0·4% are inferior, and it appears, therefore, that titanium carbide rather than chromium carbide is to be preferred as a precipitant, and that the amounts of carbon, molybdenum, and titanium should be adjusted to avoid precipitation of chromium carbide.

TABLE X—*The Effect of Carbon Content on the Constitution of the Precipitate*

| Carbon Content, % | Composition of Precipitate* | | | |
|---|---|---|---|---|
| | Mo, % | Cr, % | Ti, % | Fe, % |
| 0·10 | 0·23 | 0·04 | 0·12 | nil |
| 0·19 | 0·30 | 0·20 | 0·08 | nil |
| 0·37 | 0·42 | 1·70 | nil | nil |
| 0·43 | 1·05 | 2·14 | 0·01 | nil |

* Expressed as a percentage of the weight of steel examined

*General*

The application of physical and chemical methods to supplement data provided by the normal creep tests must be carried out with caution and judgement. Such work cannot replace creep testing. It does, however, enable a much more logical approach to be made in the problem of modifications in composition, and thus very often reduces the number of experimental alloys which have to be made and tested in creep.

### (3) Large Austenitic Steel Forgings

Owing to the increased strength of austenitic steels at high temperatures, such materials have to be worked more carefully than ferritic steels; the forging range is smaller due to the fact that the lower temperature limit of the forging range is higher; smaller reductions under the press or hammer are essential, since once a major transverse crack is produced the forging usually has to be scrapped. The removal of minor defects before re-forging, by means of chipping or by the oxy-acetylene torch, is only occasionally possible.

Apart from these restrictions on the forging operation, which are to be expected from the inherent properties of the austenitic steels, there is an additional problem which is quite a serious one, namely, the internal structure and soundness of austenitic steel ingots is, in general, inferior to that of the ferritic steel ingots.

The length of the columnar crystals is larger, and the equiaxed material which completes the central part of the cross-section of the ingot is, in general, characterized by marked looseness. This central unsoundness, whilst present in all austenitic materials, is of particular importance in the steels possessing high creep resistance.

#### (a) *Austenitic Steel Ingots*

Figure 22 shows a section of an 18/8 ingot. It will be seen that although excellent feeding has been achieved, there is central looseness in the top two-thirds of the ingot. On sheet and bar, where large reductions take place, this looseness is completely eliminated and a sound product is achieved. In a forging, where the reduction is much smaller, this unsoundness is not disposed of so readily. Moreover, if the material is difficult to forge in the as-cast condition, this central looseness may often give rise to cracking, starting from the central zone of the ingot and working out to the surface, *see* Fig. 23 (R. ex 78).

R. ex 78 is not a simple material to forge, and at an early stage Hatfield put in hand an extensive investigation on ingot design and casting practice,

with a view to effecting an improvement. Some 50 ingots of different types were examined by sectioning, covering such modifications in technique as mould shape, variations in mould material, casting temperature, and feeding arrangements, and some of the results will be indicated here.

Figures 24, 25, and 26, of ingots made in chill moulds of different taper, show the central looseness clearly, and indicate that even an abnormally high degree of taper does not eliminate the difficulty.

Figure 27 is a section of ingot cast in a chill mould with a refractory bottom. Figure 28 is a similar ingot chill cast, the head being kept hot with an oxy-acetylene torch. The feeding arrangements on both of these ingots are exceptionally good, nevertheless, the central unsoundness is still not entirely eliminated. Figures 29 and 30 show sections of two sand-cast ingots. These are quite sound. Figure 31, of an ingot cast in a composite mould, one side being made of refractory, is interesting ; this, too, is quite sound, it will be noted that the sand-cast ingots show quite a large zone of equiaxed crystals.

It appears from the above longitudinal sections that in the normal ingot mould the rate of solidification and overall rate of cooling is too rapid to enable the feeder head to operate satisfactorily. The refractory mould gives the correct conditions for a sound centre, but unfortunately the ingots so produced (probably because of their coarse structure) were very susceptible to surface cracking. Consequently this solution was not a practicable one as far as large ingots for forging were concerned.

No simple solution was forthcoming for a sound ingot of normal dimensions, say greater than 1 ton in weight, from any of the above experiments, and the method of manufacture used for bar and very small forgings was to use a normal commercial ingot forged into a slab, and to remove the centre by machining.

The 3-winged ingot was also tried and subsequently used a good deal. Figure 32 gives a sketch of the general arrangement. In this case the weakness is in a part of the casting which is discarded and the wings are free from central unsoundness,* Fig. 33. Large ingots of this type were used for the production of disc forgings and are quite successful. The method appears an expensive one at first sight, due to the high initial discard and machining costs, but for certain sizes and shapes of forgings the extra reliability more than compensates for the high initial cost.

### (b) *Properties of Austenitic Steel Forgings*

Although this detailed investigation of ingot practice has not led to the production of very large R. ex 78 forgings, the largest weighed about 11 cwt. and was in the form of a turbine rotor shaft of 23 in. diameter, tapering down to 6 in. diameter, the knowledge gained was very useful in handling some of the less difficult steels and in developing the optimum forging technique for austenitic steels generally.

R. ex 337A is a somewhat easier material to handle than R. ex 78 both as regards the production of ingots and hot working. Even so, it is unlikely that without modification in composition it will be possible to extend the size of forging available to one appreciably greater than that quoted for R. ex 78.

The forging of the 18/10 range of steels stabilized with columbium or titanium is a much simpler proposition.

Figure 34 shows a section of an F.C.B. forging, of maximum diameter 25 in., produced from a 10-ton ingot, and the forging procedure has been such that no weakness exists at any point along the centre of the forging, even at the points where the rapid change in section occurs. Of the two methods of set down, the tapered set down gives greater grain refinement at the centre.

* The cavity at the top of Fig. 31 is associated with the feeding arrangements.

TABLE XI—*Properties of F.C.B. Forging*

| Position | Direction of Tests | Physical Properties at Room Temperature | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Proof Stress, tons/sq. in. | | | Maximum Stress, tons/sq. in. | Elongation, % | Reduction of Area, % | Izod, ft. lb. |
| | | 0·05% | 0·10% | 0·50% | | | | |
| Shaft, outside | Longitudinal | 15·2 | 16·7 | 19·35 | 39·2 | 57 | 62 | 99, 90, 101 |
| Shaft, core | Longitudinal | 14·0 | 15·4 | 18·1 | 38·4 | 59·5 | 61 | ... |
| Body, outside | Longitudinal | 12·3 | 14·9 | 16·6 | 37·2 | 63 | 62 | 83, 89, 86 |
| Body, midway | Longitudinal | 11·4 | 12·35 | 14·8 | 37·2 | 58 | 54 | 88, 75, 89 |
| Body, core | Longitudinal | 10·9 | 11·95 | 14·5 | 37·6 | 55·5 | 52 | 89, 75, 87 |
| Shaft, outside | Tangential | ... | ... | 15·7 | 38·6 | 47 | 48 | 41, 38 |
| Body, outside | Tangential | 17·05 | 17·7 | 18·85 | 37·6 | 44 | 32 | 42, 40, 38 |
| Body, midway | Tangential | 12·5 | 13·6 | 15·85 | 34·0 | 27 | 23 | 26, 22, 27 |
| Body, midway | Radial | 12·5 | 14·0 | 16·6 | 35·8 | 35·5 | 30 | 28, 25, 30 |

The mechanical properties of the forging are given in Table XI ; the proof stresses of material from the interior of the shaft are somewhat lower than those quoted for rolled bar, Table IX (*e*), as might be anticipated ; the ductility throughout is excellent. Typical creep tests are given in Fig. 36 and are seen to be somewhat superior to bar of similar composition.

An F.C.B. creep test-piece which, after testing at 650° C. under a load of 4 tons/sq. in. for some 6600 hr., has been cooled to room temperature and then subjected to the normal tensile test. The mechanical properties, proof stress, etc., were very similar to those of material in the initial condition, *see* Table IX (*g*). The elongation obtained was 50% and the specimen was free from intercrystalline cracking of any kind.

Figure 35 is a composite photograph of three finished rotors, the larger one being produced from a 25-ton ingot and having a body diameter of $26\frac{1}{4}$ in. and a finished weight of 5 tons. The mechanical-test results on these forgings were similar to those quoted in Table XI. and as far as could be ascertained by the usual boroscopic and supersonic method they were quite sound.

As already indicated, this type of material gives a creep performance intermediate between that of the 18/8 material and that of R. ex 78, *see* Fig. 3, and does not require any high-temperature solution treatment. It is highly probable that still larger forgings may be practicable using this type of steel.

No marked additional difficulties in forging are introduced when additions of molybdenum and/or cobalt are made to steels of the F.C.B. type. Enhanced creep properties intermediate between R. ex 78 and R. ex 337A can be obtained in such materials in small ruling sections after suitable high-temperature solution treatments. In large forgings, however, the problem of carrying out such treatments and ensuring that they are effective has not yet been solved.

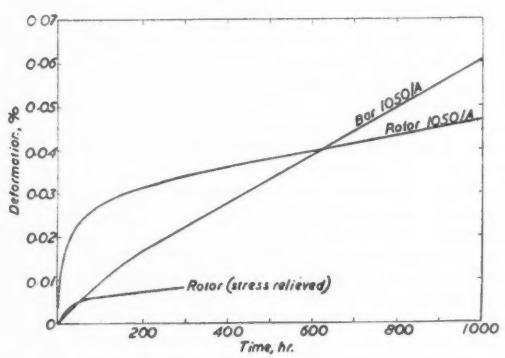


FIG. 36—Typical creep test at 4·0 tons/sq. in. and at 750° C. on F.C.B. bar and forging

## (4) CONCLUSIONS

In the foregoing sections I have outlined the experimental work Hatfield conducted subsequent to 1938, on steels for use at elevated temperatures. There is no doubt that his work on R. ex 78, the first of the present class of high creep-resisting steels, deserves to rank amongst his greatest achievements, and it is fitting, therefore, that this reference to it should go on record.

In reviewing the present position, it appears that for the temperature range up to 550° C. no technological difficulties are likely to prevent the production of quite large forgings capable of meeting the requirements of engineers, both as regards stress and life, either in ferritic or austenitic steel. For the temperature range from 550° to 650° C., large forgings of suitable properties can be produced in the simpler austenitic steels. Beyond 650° C. the position on large forgings, say greater than 1 ton in weight, is still experimental. (This upper temperature limit may be increased for short term applications or for very low stresses.)

Steels with the appropriate properties in bar form are available, which can be handled without undue difficulty in the forge, but certain metallurgical problems remain.

Solution treatments at 1250° C. or similar temperatures, whilst possible on bar and small forgings, are not easily carried out on large forgings. Oxidation is serious and there is very little margin between the treatment temperature and burning, consequently temperature control must be excellent. No doubt these difficulties will be overcome ; it is primarily an engineering problem of furnace design and control of atmosphere and temperature. The rate of cooling from the solution-treatment temperature is important, it must be sufficiently high to prevent precipitation in the high-temperature range, say 900°–1250° C. Size associated with the low thermal conductivity reduces the maximum cooling rate which is possible, and consequently an alloy mixture giving satisfactory results in bar is often quite unsuitable for large forgings. Thus, even in austenitic steels we must now look for a mass effect, and adjust the composition to ensure that after the solution and precipitation treatments the creep properties at the centre of large forgings are comparable with those at the surface.

Although segregation of sulphur and phosphorus is relatively unimportant, segregation of some of the important alloying elements of these complex steels may occur in large ingots, leading to the presence of low-melting-point phases. At the high solutionizing temperatures this can give rise to burning or incipient fusion in large forgings, an effect not noticed on material from small ingots.

Finally, there is the economic aspect. Many of these new materials are expensive in the ingot, due to the raw materials used, but an equally important item in the cost of the final forging is the actual cost of forging. The number of heats required, even with a relatively simple material like F.C.B., is from five to ten times the number required for a ferritic-steel forging of the same size. This will decrease somewhat with greater experience, but it seems inevitable that as the hot strength of the materials improves, the forging time will increase.

One technical factor of great importance which has not been mentioned in this Lecture is the subject of the fatigue properties of high-temperature materials. At elevated temperatures it appears that there is no such property as the fatigue limit as observed in steels at room temperature. The strength diminishes continuously as the number of applications of stress increases. Here is a new field of metallurgical research and it seems reasonable to predict that investigations just as comprehensive and time consuming as those carried out at present on creep properties will be necessary before really adequate information on the fatigue properties of the various materials becomes available.

The above factors represent the main problems before the metallurgist dealing with the production of large forgings for service at high stresses in the temperature range above 650° C. They are all reasonably straightforward and, although it will take some time to resolve them all, there is no doubt that large forgings will be forthcoming with high-temperature properties superior to those of the large forgings at present available.

### Acknowledgments

The various investigations on creep performance described in this Lecture were carried through by Mr. L. Rotherham and the Earl of Halsbury. Mr. J. M. Morley is responsible for the excellent metallographic work on the R. ex 78 class of materials.

The production of the large ingots and forgings has been handled by the Works' personnel of Messrs. Thos. Firth and John Brown, Ltd., who have shown marked ingenuity and patience throughout the various 'teething' stages.

I am indebted to Mr. H. W. Kirkby for assistance in preparing this paper, and to Miss A. K. Osborne for compiling the bibliography.

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## BIBLIOGRAPHY ON CREEP- AND HEAT-RESISTING STEELS

## (COVERING THE PERIOD 1937 TO 1947)

**Investigation of Chromium–Nickel Austenitic-Martensitic Steel.** Y. B. Fridman. (Metallurgist, Russia, 1937, vol. 12, No. 5, May, pp. 63–75). The author discusses the group of steels intermediate between the high-alloy austenitic type and the lower-alloy martensitic type; a steel containing 0·35% carbon, 13·3% chromium, 8% nickel, and 2·8% silicon is considered. Quenching from 1100° C. produces an entirely austenitic structure, while annealing at 700–900° C. causes the breakdown of the solid solution of chromium carbides in the austenite which becomes unstable. By suitable treatment, a mixed martensite-austenite structure is obtained since the pure austenite decomposes in the temperature interval 140°–120° C.; this structure is associated with a high degree of hardness. In this class of steels no austenite→martensite transformation occurs above 0° C. unless the carbides have been removed from solid solution by annealing, and there are no intermediate products such as sorbite or troostite. The increase in hardness due to the separation of carbides is particularly important when the steel is to be employed at high temperatures.

**The Ageing of Heat-Resisting Austenitic Steels.** Y. B. Fridman. (Kachestvennaya Stal, 1937, No. 5–6, pp. 52–57, in Russian). A study was made of the ageing process in two austenitic heat-resistant steels, the first of which contained 19·3% chromium, 25·5% nickel, and 2·8% silicon, whilst the second contained 13·5% chromium, 14·4% nickel, and 2·5% tungsten. The effect of quenching from between 900° and 1400° C. on the physical and mechanical properties of the steels was studied, and it was shown that changes in these properties reflect the dissolution of carbides, the grain growth, and other phenomena which occur on heating to the higher quenching temperatures. The increase in the

impact resistance with dissolution of the carbides is particularly marked. The ageing process between 600° and 900° C. was followed by hardness measurements, both at constant temperature during various periods of time and on heating to various temperatures for a fixed time. In tungsten-bearing steel, two distinct ageing stages, due to precipitation of the carbides of chromium and tungsten, respectively, were noticed. Finally, it was shown that cold deformation lowers the temperature at which ageing begins and also accelerates the process. The results of all the investigations were used to establish suitable heat-treatments for these steels.

**Chromium-Manganese Steels as Heat-Resisting Steels.** J. H. G. Monypenny. (Metallurgia, 1937, vol. 17, Nov., pp. 7–12). Following a preliminary discussion on the composition and requirements of heat-resisting steels, the author considers the chromium–manganese steels containing 18% chromium and manganese contents from 7·0% to 16% and over. The metallography, the effects of heat-treatment, the effects of varying the composition, and the physical properties of the steels are considered; the most suitable alloy of the class is said to be that containing 0·15% carbon and chromium not above 15·0%. This steel, with the requisite manganese, is entirely austenitic; the ferritic steel is unsuitable for heat-resisting purposes.

**Heat Resisting Steels.** Sir Robert Hadfield. (Mond Nickel Co., Ltd., Bureau of Information on Nickel, Publication F 4). The author describes briefly the mechanism of the scaling of steel, outlines the evolution of heat-resisting steels, and describes their resistance to scaling and corrosive gases, their strength and stability at high temperatures, their resistance to wear and impact, and their incorporation into equipment designed for high-temperature work. Some discussion is included on the application of the steels to various specific purposes.

**Concerning New Stainless Acid-Resisting and Non-Scaling Steels and Their Use.** H. Hougardy and G. Riedrich. (Metallwirtschaft, 1937, vol. 16, Dec. 17, pp. 1329–1342). The authors discuss in detail the compositions, properties, and applications of the ferritic, martensitic, and austenitic acid-resisting steels and non-scaling steels. In respect of acid-resisting steels, special attention is paid to resistance to chemical attack by various corrosive media, to workability, and to weldability. Clad materials are dealt with in the final section of the article. Data are presented in tabular and graphical form.

**Developments and Applications of Acid- and Heat-Resisting Steels.** W. H. Hatfield. (Metallurgia, 1937, Vol. 17, Dec., pp. 53–55). The applications of both acid- and heat-resisting steels in the engineering, aircraft, and automobile industries, and miscellaneous applications are noted. Reference is made to a steel specially adapted for turbine blading.

**Chrome–Molybdenum Steels.** W. F. Chubb. (Iron and Coal Trades Review, 1937, vol. 135, Dec. 24, pp. 1043–1044; Dec. 31, pp. 1086–1087). Structural steels containing 0·25–0·35% carbon, 0·5–0·8% chromium, and 0·15–0·25% molybdenum, high chromium–molybdenum steels for the manufacture of components subjected to impact stresses at high temperature, and special creep-resistant chromium–molybdenum steels are discussed, together with high-duty steels for the oil industry. The heat-treatments of the steels are dealt with and tabular data presented regarding their mechanical properties.

**Mechanical Properties of Some Special Steels at Low and High Temperatures.** E. S. Tovpenez. (Kachestvennaya. Stal, 1937, No. 3, pp. 47–48). The author has investigated the mechanical properties, in the temperature range of −60° to 600°, of the following four steels: (A) 2·44% chromium, 1·38% nickel, 0·35% molybdenum; (B) 0·32% chromium, 3·32% nickel, 0·38% molybdenum; (C) 0·96% chromium, 0·43% molybdenum, 0·17% vanadium; and (D) 1·12% chromium, 0·44% nickel, 0·34% molybdenum. The change in properties with temperature is smoother in special steels than in carbon steels, and the decrease in notch toughness at low temperatures (as well as at 450°) is slighter. The limit of proportionality and the temporary resistance are larger than in carbon steel and remain rather high even at 600°. Between −40° and +150° the mechanical properties of the special steels investigated were practically constant, especially of steels A and B.

**Steel for High Vapour Pressures and High Temperatures.** G. T. Liberman. (Kachestvennaya Stal, 1937, No. 3, pp. 29–35). The author has investigated the properties of five steels: (1) 1·09% manganese, 0·39% silicon, 0·58% molybdenum; (2) 1·10% manganese, 0.36% silicon, 0·52% molybdenum, 0·72% chromium; (3) 1·11% manganese, 0.30% silicon, 0·24% molybdenum, 1·05% copper; (4) 0·37% manganese 0·87% silicon, 0·61% molybdenum, 1·11% copper; and (5) 0·52% manganese, 0·30% silicon, 0·60% molybdenum, 0·35% aluminium. The main subjects of the paper are the mechanical properties of the five steels investigated at temperatures up to 700° C.; their ageing; and oxidation by air and water vapour. The highest heat resistance was shown by the chromium–manganese–molybdenum steel No. 2. This steel was superior to the chromium–nickel–molybdenum and chromium–silicon–molybdenum steels now in use as heat-resisting materials. Satisfactory results were also obtained with the manganese–molybdenum steel No. 1. The addition of copper to steels Nos. 3 and 4 was not especially favourable with regard to ageing. The addition of aluminium, as in steel No. 5, prevented ageing but impaired the mechanical strength of the metal. It is therefore advisable to use aluminium in quantities smaller than those used in the preparation of steel No. 5, *e.g.* 0·1–0·15%.

**New Equipment for Creep Tests at Elevated Temperatures.** P. G. McVetty. (Proceedings of the American Society for Testing Materials, 1937, vol. 37, Part 2, pp. 235–257). A creep-testing machine is described which enables twelve to sixty tests at different stresses to be made in the same furnace.

**The Behaviour of Steels at High Temperatures, Progress Report.** O. Leihener and P. Grün. (Korrosion and Metallschutz, 1937, vol. 13, Oct.–Nov., pp. 354–365). Heat-resisting steels are considered in the concluding pages of the article, the effects of various alloy constituents being noted and the influence of environmental conditions examined. Tabular and graphical data are presented.

**Development of Non-Scaling and Heat-Resistant Steels in Russia.** A. B. Borzdyka. (Kachestvennaya Stal, 1937, No. 11, pp. 46–48). A short review of the developments in the production of non-scaling and heat-resisting steels as well as of steels for electrical resistance-heating elements is presented. A list of compositions of medium-alloy, high-chromium, Silchrome, chromium–nickel (austenitic), and Nichrome and chromium–aluminium steels produced in Russia is given.

**Chromium–Molybdenum–Manganese and Chromium–Tungsten–Manganese Heat-Resisting Steels.** A. M. Borzdyka. (Kachestvennaya Stahl, 1937, No. 8, pp. 33–36). The author reviews some of the previous work as well as his own investigations on the effect of additions of tungsten or molybdenum to steels containing chromium 18% and manganese 8%. Steels containing one or other of these elements appear to possess certain properties which would make them suitable substitutes for chromium–tungsten–nickel steel and it seems that molybdenum may take the place of tungsten.

**The Influence of Remelting in a Vacuum on the Quality of Heat-Resisting Iron Alloys of High Electrical Resistance.** P. S. Lebedev. (Kachestvennaya Stal, 1937, No. 9, pp. 18–27). In general the vacuum process of melting appears to be a very valuable one in dealing with this type of alloy. Hot mechanical working of these heat-resisting alloys, which normally constitutes the most difficult technological operation in their production, is considerably facilitated as a result of melting in a vacuum. This improvement appears to be due to the absence of gasses in the vacuum-melted alloys.

**Relaxation Tests on Specimens of 0·35% Carbon Steel (K20) at 454° C.** N. L. Mochel. (Transactions of the American Society of Mechanical Engineers, 1937, vol. 59, pp. 543–455). The author describes a series of tests on specimens of 0·35% carbon steel in which the permanent set produced by keeping the specimen under load at 454° C. for a period of 50 hr., followed by two periods of 100 hr. and one period of 250 hr., was measured, successive specimens being subjected to tensile stresses of 2·23, 4·45, 8·9 tons/sq. in.

**Design of Members Subjected to Creep at High Temperatures.** J. Marin. (Transactions of the American Society of Mechanical Engineers, 1937, vol. 59, pp. A21–A24). The author discusses the stresses in machine and structural members subjected to high temperatures as determined by theories advanced by R. W. Bailey and St. Venant. He shows that the theoretical results of each are all in agreement with the test results.

**A Relaxation Test on 0·35% Carbon Steel (K20).** E. L. Robinson. (Transactions of the American Society of Mechanical Engineers, 1937, vol. 59, pp. 451–452). The author discusses a "flow-rate test" which is intended to stimulate what happens in a bolt in an unyielding flange. In this test a relatively high initial stress is applied, but a specified total extension is not exceeded; the initial creep is rapid, and the applied load is reduced each time the total extension reaches the specified limit. The author presents a mathematical discussion of the results obtained on testing a specimen of 0·35% carbon steel in this manner.

**Constant Strain-Rate Tests on 0·35% Carbon Steel (K20) at 454° C.** A. Nadai and E. A. Davis. (Transactions of the American Society of Mechanical Engineers, 1937, vol. 59, pp. 447–450). The authors report upon an investigation by means of accelerated tests of the effect of the rate of deformation upon the yield stress of metals at high temperatures. In this case stresses were applied to produce a constant rate of strain on specimens of a 0·35% carbon steel at 454°C.

**Nickel-Free Heat-Resistant and High-Strength Steels.** L. Liberman and P. Strelets. (Kachestvennaya Stal, 1937, No. 4, pp. 11–21; Chem. Abs., 1938, p. 4501). Steels with C 0·25%, Cr 18–20%, Cu 2·5%, Si max. 2·0%, Al max. 2·0% have good oxidation resistance up to 900° and satisfactory at 1000°, though their mechanical properties are so poor as to permit their use only with light loads. Alloys with Co 6–0·65, Cr 6–8, Si 2, Al 2·5–3·0% with addition of 2·0% tungsten, or 1·0% molybdenum or 0·3% vanadium have the same mechanical properties at elevated temperatures as steels without such additions but have a much greater resistance to oxidation. The best strength at elevated temperatures among Cr–Mn steels was found in alloys containing Cr 18, Mn 8, and Mo 2–3% which were as strong as 18 Cr–8 Ni steels though the latter had better oxidation resistance. Additions to this steel of Al or Si pronouncedly decrease its strength at high tempertures while Be also has a deleterious effect.

**Reactions during Attacks on Heat-Resistant Steels by Hot Gases.** E. Houdremont and G. Bandel. (Proceedings of the International Association for Testing Materials, London Congress, 1937, pp. 163–167).

**Replacement of Highly Alloyed Steels in Power Plants at High Temperatures.** F. Wiese. (Elektrizitätwirtschaft, 1937, vol. 36, p. 664). The author claims that efforts to replace highly alloyed steels by low alloys have been largely successful. The alloying additions such as silicon, manganese, and vanadium can be produced in Germany. Molybdenum is not a home product but is used only in small quantities and with 3% chromium will replace chromium and nickel additions of up to 25%. The weldability of such low-alloy steel is, on the whole, ensured if the correct welding and alloying material are used.

**Investigation of an Aluminium–Iron Heat-Resisting Alloy.** A. S. Saimovsky, N. F. Drosdov, and K. V. Nashokin. (Kachestvennaya Stal, 1937, No. 1, pp. 36–40). The authors have investigated an alloy containing 12% of aluminium and 2% of chromium. It is malleable and can be rolled; wire-drawing requires some precautions, because of insufficient toughness. Its electrical resistance is 1·25 ohm per sq. mm. per m., with a temperature coefficient of $3 \times 10^{-4}$. It is sufficiently heat-resistant to be used at 1200° C.

**Chemical Resistance of Chromium and Aluminium to Sulphur Vapours at High Temperatures.** V. K. Pershke. S. S. Gstev, and I. V. Oknin. (Khim. Mashinostroenie, vol. 6, No. 4, 1937, pp. 27–30: Chem. Abs., 1938, Nov. 20, p. 9016). Up to 700°, "Fechral" (a ferritic alloy containing 12–14% chromium, 3–5% aluminium, and 0·15% carbon) and Chromal exhibit satisfactory resistance to sulphur vapours whereas materials such as boiler plate, chromium steel, nickel steels, etc., under the same conditions undergo such strong corrosion as to render them useless. Chromal is twice as resistant as "Fechral." The optimum proportions of the alloying metals are chromium 13–14 and aluminium 4–5%.

**Chromal, Its Properties, Rolling, Drawing, and Annealing.** V. Erakhtin and A. Shchetkina. (Kachestvennaia Stal, 1937, No. 9, pp. 42–46; Metals and Alloys, 1938, Apr., p. MA 249). An alloy with 0·11% carbon, 1·24% silicon, 30% chromium, 3·86% aluminium was investigated. Its resistance to impact crushing at 800–1100° C. is between that of high steel and soft steel. Annealing at 600–800° C. produces the best properties and corresponds to complete recrystallization. Heating cold-worked alloy above 900° C. leads to grain coarsening. Faster cooling (*e.g.* in water) after annealing reduces tensile strength and increases reduction of the area, slower cooling (air of furnace) increases tensile strength and reduces reduction of area. Elongation is but slightly affected by the cooling rate.

**The Choice of Materials Resistant to Corrosion under Superheating Conditions of High Pressure Boilers.** E. I. Shmaenok. (Korroziya i Bor'bas Nei 3. 1937; No. 1, pp. 75–6: Chem. Abs., 1939, Sept. 10, p. 6778). The resistance of 25 steels in contact with steam was investigated. In some experiments the gaseous mixtures contained besides the steam, carbon dioxide or carbon monoxide and oxygen. The experiments were performed at 400–600° under atmospheric pressure, and with water-vapour

pressures of 50, 100, and 200 atmospheres. Maximum resistance was shown by chromium steel (15–17% chromium), chromium–nickel steel (18–8), and silicon–chromium steel. The chromium–tungsten was more resistant that the chromium–molybdenum steel.

**Resistance to Heat.** (Metallurgical Progress, Recent Advances in Steel Alloys, Trade and Engineering, 1937, Apr.). A series of pearlitic nickel steels has been developed for the purpose of resisting temperatures as high as 1100° C. They are less expensive than the standard heat-resisting steels and their resistance to heat and oxidation is not so high, but they offer much greater resistance than, for example, the ordinary carbon steels. The demand for a material with high resistance to scaling or oxidation under heat has led to the introduction of a steel with 25% chromium and 20% nickel, which has given satisfactory results under test. Short-period experiments at ordinary room temperature and at temperatures between 70 and 700° C. have been carried out, in order to ascertain the physical characteristics. The steel proved quite capable of withstanding furnace temperatures and furnaces atmospheres, giving at the same time a great degree of resistance to mechanical stress, together with considerable corrosion-resistance under heat.

**Some Alloys for Use at High Temperatures. Part IV—The Constituents of the Alloys of Nickel, Chromium, and Iron.** C. H. M. Jenkins, E. H. Bucknall, C. R. Austin, and G. A. Mellor. (Journal of the Iron and Steel Institute, 1937, No. 2, pp. 187–222). This report is divided into four sections: (*a*) Cr–Fe alloys, (*b*) Ni–Fe alloys, (*c*) Ni–Cr alloys, (*d*) Ni–Cr–Fe alloys. As regards (*a*) no experimental work has been done and reference is made to the works of Adcock, Wever, and Jellinghaus, Eriksson, and Jette and Foots. The later work indicates the slow production of a compound phase of composition FeCr at low temperatures, in the region between 37 and 60 per cent. Cr. The limit of the δ loop is placed at 11·6 per cent. Cr.

**Pipes, Valves and Turbines for High Temperature Steam.** (Metal Progress, 1937, vol. 31, June, pp. 635–640). To investigate the possibility of using higher temperatures in steam plant, the Detroit Edison Company has built two experimental installations. In plant No. 1 18/8 chromium–nickel steel was selected for all parts. Tubing was to the specification: carbon not more than 0·16, chromium 17–20, nickel 8–10%. Valves, flanges, and de-superheaters were of a modified form of 18/8 containing up to 0·25% carbon, and silicon less than 2%. Materials used in plant No. 2, were similar, except that the superheater-tubing steel contained silicon up to 2·5% added to combat the sulphur attack of the oil used for firing. Castings for the high-temperature parts of the turbine were of nickel–chromium–molybdenum steel and the turbine rotor and wheels were machined from a forging of the same steel. Buckets were of nickel 36, chromium 12, carbon 0·25%. Certain of the valve bodies were of steels containing nickel 1·05, chromium 0·70, molybdenum 0·40%, and turbine wheels were made from nickel–chromium–molybdenum steel forgings. A table showing mechanical properties and impact, in the original condition and after 6408, 15,535, 21,946 and 35,655 hours of service, indicates that although gradual slight embrittlement has occured, the properties are still excellent.

**The Scaling of Steel Wire and Its Effect on Subsequent Working.** F. Körber and W. Asbeck. (Mitteilung aus dem Kaiser-Wilhelm Institut für Eisenforschung, 1937, vol. 19, pp. 161–185).

**Advantages of Columbium in Wrought 4 to 6 per cent. Chromium Steel.** (Electrometallurgical Company, Unit Union Carbide and Carbon Corporation). Curves show the excellent creep strength (1% creep in 10,000 hr.) of columbium-bearing 4–6% chromium steels. Improved values are obtained by the addition of molybdenum.

**Use of Scale-Resistant Steels for Salt-Baths with Nitrates.** W. Geller. (Aluminium, 1937, vol. 19, pp. 647–648). The action of the nitrate at high temperatures in tanks made of mild steel, chromium steel, chromium–nickel steel *A*, chromium–nickel steel *B* (higher alloyed than the former) was investigated for a melt of $KNO_3$ + $NaNO_3$ in the ratio 1 : 1 at 650°. Scaling of the alloy steels by the melt is very small and the ignition temperatures for an active exothermic reaction between tank and melt is very high so that practically no danger of explosion exists. The alloy steels are much more resistant to corrosion and heat and can, therefore, be made of smaller thickness than mild steel or iron containers; this assures better heat transfer.

**Influence of Silicon Additions on High-Temperature Characteristics of 4–6% Chromium–Molybdenum Steels.** L. Clark and M. Fleischmann. (National Petroleum News, 1937, vol. 29, No. 44, pp. R–274, 276, 280–1). A content of 1·5% silicon in 4–6% chromium–molybdenum steels increases surface stability to oxidation and the structural stability and thus indirectly improves load-carrying ability and ductility up to fracture at elevated temperatures.

**Heat-Resistant Steels.** J. Biren. (Revue Technique Luxembourgeoise, 1937, vol. 29, Nov.–Dec., pp. 249–270). After a preliminary discussion on the purpose of heat-resisting alloys and steels in particular the author briefly discusses the physical, chemical, and mechanical conditions which such steels may encounter in service. The materials are then considered under the following headings: those subjected to mechanical stressing alone, to mechanical stressing combined with chemical attack at temperatures below 600° C.; steels resistant to temperatures above 600° C. with exposure to oxidizing and other corrosive gases; similar steels under like conditions subjected in addition to simultaneous mechanical stressing. Tabular data are presented regarding the compositions and physical and mechanical properties of the steels concerned.

**Discrepancies in the Load-Carrying Abilities of Carbon Steels at 454° C.** H. W. Gillett. (Proceedings of the American Society for Testing Materials, 1937, vol. 37, Pt. 1, pp. 187–192). Very large differences in steels are noted from the point of view of load-carrying ability at high temperatures.

**Report of Long-Time Creep Tests of 18% Chromium, 8% Nickel Steels and 0·35% Carbon Steel.** H. C. Cross and J. G. Lowther. (Proceedings of the American Society for Testing Materials, 1937, vol. 37, Pt. 1, pp. 178–186). A continuing progress report shows that the rate of deformation for the 18% chromium, 8% nickel steel has slowly but steadily increased since the previous report (15,185 hr.), to the present (17,994 hr.). The long-time creep tests on the 0·35% carbon steel at 8000–7500 lb./sq. in. at 455° continue to indicate extrapolation from the 2000-hr. period as conservative compared with the actual deformation measured.

**Heat-Resisting (Metallic) Materials for Temperatures up to 600°.** W. Tofaute and W. Ruttmann. (Wärme, 1937, vol. 60, pp. 703–709). The properties desirable in steels for use at 300–600° and the effect of various alloying elements on the mechanical properties are discussed. The composition, elastic limit, and fatigue strength of plain and alloyed steels used for boilers, turbine casings, blades, etc., are tabulated. The fatigue properties of welded Mo, Cu–Mo, and Cr–Mo steels differ little from those of unwelded specimens. The possibilities of developing steels for more severe service are discussed.

**Chromium–Manganese Steels as Heat-Resisting Steels.** J. H. G. Monypenny. (Metallurgia, 1937, vol. 17, Nov., pp. 7–12). Structural characteristics of Cr–Mn steels are discussed, particularly as affected by prolonged heating at high temperatures. The austenitic steels may be useful, but the ferritic steels show little promise. Recent work on Cr–Mn steels is reviewed.

**Steels and Their Utilization for High Steam Pressures and Temperatures.** R. W. Bailey. (Transactions of the Institute of Marine Engineers, 1938, vol. 50, pp. 93–113). The author reviews the important aspects of creep metals and their utilization for high-temperature-steam-plant service, and design factors to be considered. A total creep of 0·001–0·003 in./in. for the life of the plant should not be exceeded. All creep-test specimens which fractured failed from the outside. Stress and not temperature is the determining factor until scaling becomes serious. The author discusses the effect of Mo, Mo–Cr, and other alloys on creep resistance and rate of weakening due to thermal action.

**Metallurgy and the Aero-Engine.** R. Pye. (Journal of the Institute of Metals, 1937, vol. 61, No. 2, pp. 19–34). Good machining qualities and the capability of responding to special surface treatment on the working face are stressed as desirable properties in a steel for aero-engine cylinder barrels. Problems connected with the resistance to scaling of valves at high temperatures and with their resistance to attack in the heated state by lead compounds are also dealt with ; reference is made to the use of steels containing 12 to 14% each of nickel and chromium and to the practice of hard-facing with Stellite, and, more recently, to the use of an alloy containing 80% of nickel and 20% of chromium for replacing Stellite. The use of sodium and mercury-filled valves for obtaining more rapid heat transference is examined.

**The Influence of Carbon on the Scaling of Chromium Steels.** W. Oertel and W. Landt. (Stahl und Eisen, 1937, vol. 57, July 8, pp. 764–766). Experiments on chromium steels of different carbon contents indicate that resistance to scaling is strongly influenced by composition and by the structure obtaining at the working temperature ; austenite is more resistant than ferrite.

**Scaling of Chromium Steels.** (Metallurgist, 1937, vol. 11, Oct. 29, pp. 70–72). The above paper of W. Oertal and W. Landt is critically reviewed.

**Heat-Resisting Steels.** W. H. Hatfield. (Journal of the Institute of Fuel, 1938, vol. 11, Apr. pp. 245–304 : Engineering, 1938, vol. 145, pp. 372–374, 455–457). Resistance to oxidation and strength at high temperatures were studied on 14 different steels. Properties and typical applications for these steels were discussed. Relative resistance to oxidation was determined as a " scaling index " which was the gain in weight in mg. per sq. cm. for 7 heating and cooling cycles at temperatures from 800 to 1200° C. Each cycle consisted of exposing the specimens for 6 hours at the prescribed temperature in a furnace atmosphere representative of an industrial furnace, and followed by cooling. Hatfield determined creep value by the " time yield " value which is the stress approximately equivalent to a rate of creep of a millionth of an inch per hour. The specimen placed under the time-yield stress should not show an extension exceeding 0·50% of the gauge length in the first 24 hours, but during the next 48 hrs. should show no further extension, within a sensitivity of measurement of 1/10,000 in. on a 2 in. gauge length. The apparatus which reads to 1/40,000 in. was fully described. The addition of molybdenum to steel greatly increases the resistance to creep in the lower-temperature range, but has no effect when 600° is reached. Chromium, which gives resistance to oxidation, does not increase the strength of the steel at elevated temperature. Substantial additions of nickel to a chromium steel give the dual result. Addition of tungsten was shown to be valuable in assisting in the attainment of higher strength. All steels of high strength at elevated temperatures were austenitic in character. Importance of proper design of parts for high-temperature service was stressed.

**Report of Joint Research Committee on Effect of Temperature on the Properties of Metals. Creep Tests of Tubular Members Subjected to Internal Pressure.** F. H. Norton. (Proceedings of the American Society for Testing Materials, 1938, pp. 118–120). Carbon–molybdenum and chromium–molybdenum steel tubes, 4 in. in dia. by 30 in. long, were subjected to 650–9240 lb. internal gas pressures. The increase in diameter was 0·0005–0·0165 in. per inch at 427° C. for the chromium–molybdenum steel, and the elongation was 0·0001–0·0006 in. For the carbon–molybdenum steel the diameter increase was 0·00025–0·00055 in. and the elongation was 0·00007–0·0001 in./in. at 566° C. For the chromium–molybdenum steel at 649° C. the diameter increase was 0·0015, and the elongation 0·0.

**Report of Joint Research Committee on Effect of Temperature on the Properties of Metals—Long-Time Creep Test of 0·35 per cent. Carbon Steel (K20).** H. C. Cross and J. G. Lowther. (Proceedings of the American Society for Testing Materials, 1938, pp. 121–129). This test at 454° C. indicates extrapolation from the 2000-hr. period to be conservative as compared with the actual deformation measured over 20,000 hr. An approximate constant rate of deformation was obtained between 4000 and 20,342 hr. This steel loaded to 7500 lbs./sq. in. showed a creep-rate change of 5 to 1 for temperature changes of 50° above or below 454° C. Tensile and impact tests on specimen 25B5 after the creep test indicate that very small and unimportant changes in physical properties occurred during the creep test.

**Report of Joint Research Committee on Effect of Temperature on the Properties of Metals—Effects of Manufacturing Variables on the Creep Resistance of Steels.** H. C. Cross and J. G. Lowther. (Proceedings of the American Society for Testing Materials, 1938, pp. 149–171). This progress report shows that the creep resistance of coarse-grained plain carbon steel at 399°, 454°, and 510° C. is superior to that of the fine-grained steels of the same chemical composition. Relaxation tests indicate that coarse-grained K20 steel is superior to the fine-grained. A carbon–vanadium steel which showed superior creep resistance to plain carbon steel when fine-grained was not improved greatly by coarsening.

**Report of Joint Research Committee on Effect of Temperature on the Properties of Metals—Acceptability Tests for High-Temperature Characteristics.** A. E. White and C. L. Clark. (Proceedings of the American Society for Testing Materials, 1938, pp. 142–146). The 1040 steel is nearly as strong at 538° C. as the K20 steel is at 454° C. as determined from the stress rupture tests. The 0·5% molybdenum steel is more susceptible to strain-hardening at 482° C. than is either of the carbon steels at 343° C. or the chromium–molybdenum steel at 427° C.

**The Scaling of Iron and Steel.** A. Farnik and F. Kaluza. (Prace Badawcze Huty Baildon, 1938, No. 3, Feb., pp. 67–73). Results are presented of an investigation on a range of steels containing 4·59% to 24·53% of chromium, 0·71% to 0·19% of carbon, 0·29% to 1·91% of silicon, 0·16% to 19·77% of nickel, and with and without tungsten, molybdenum, and vanadium. Scaling tests were conducted at 900°, 1000°, and 1200° C. in oxidizing atmospheres with and without additions of aqueous vapour. Losses due to scaling are represented

graphically in milligrammes per square centimetre for periods of exposure up to 20 hr.

**Damage to Muffles by Controlled Atmospheres.** (Metal Progress, 1938, vol. 33, Mar., pp. 277–280). Muffles, resistors, and thermocouples made of heat-resisting alloys of the nickel–chromium–iron type may be attacked by heated, reducing, and carburizing gases, the latter particularly tending to react with these materials. The gases appear to penetrate the protective oxide skin. The site and mechanism of deterioration due to the absorption of carbon at high temperatures are discussed.

**Heat-Resisting Alloy Castings.** H. Dixon. (Industrial Heating, 1938, vol. 5, Mar., pp. 224–234). A review of the discussion on heat-resisting castings held by the Cleveland Chapter of the American Society for Metals. The history, fundamental physical, chemical, and structural characteristics, and the compositions of suitable alloys were discussed, and problems of the design of equipment cast in such alloys and the service life of equipment were also dealt with. Data in tabular and graphical form are presented.

**Investigation of the Suitability of Heat-Resisting Materials for Internal-Combustion Engines.** F. Bollenrath, H. Cornelius, and W. Bungardt. (Metallwirtschaft, 1938, vol. 7, July 15, pp. 755–757). The authors have carried out a research on a number of heat-resisting materials, to determine their suitability for use in the construction of internal-combustion engines. Twenty-four alloy steels and other alloys were investigated; their compositions are listed in a table, in which the "marks" of the manufacturers are also given. The research included loading tests above the creep limit, the determination of the resistance to alternations of temperature, the observation of microstructural changes on annealing, and scaling experiments. The stresses giving rise to a total elongation of 1% in 300 hours at temperatures of 600°, 650°, and 700° C. are tabulated, while another table shows the relationship between these loads and the specific gravity of the material.

**Stainless and Heat-Resisting Steels.** L. Sanderson. (Canadian Metals and Metallurgical Industries, 1938, vol. 1, June, pp. 179–181). The author summarizes some of the outstanding contributions to the improvements of stainless and heat-resisting steels.

**The Properties of Heat-Resisting Steels.** (Nickel Bulletin, 1938, vol. 2, Aug.–Sept., pp. 180–181). A table is given of the physical and electrical properties of six heat-resisting steel alloys of the following compositions: (*a*) chromium 18%, nickel 8%, tungsten 1%, titanium 1%; (*b*) chromium 14%, nickel 14%, tungsten 3%; (*c*) chromium 23%, nickel 12%, tungsten 3%; (*d*) chromium 20%, nickel 8%, tungsten 4%; (*e*) chromium 15%, nickel 30%, tungsten 4%; and (*f*) chromium 25%, nickel 20%.

**Behaviour of Steel at Elevated Temperatures.** A. Pomp. (Stahl und Eisen, 1938, vol. 58, Apr. 21, pp. 432–435; Apr. 28, pp. 459–461). The author reviews the literature dealing with the mechanical properties of steels at elevated temperatures and with apparatus for investigating such mechanical properties.

**Chromium–Manganese Steels as Heat-Resisting Steels.** J. H. G. Monypenny. (Metallurgia, 1938, vol. 17, Jan., pp. 93–96). (Continuation of previous article). Steels are considered in regard to their physical and mechanical properties and resistance to scaling. The maximum chromium content must be restricted to prevent the formation of any appreciable amounts of ferrochrome, and those steels suitable for practical use exhibit adequate resistance to scaling in air up to a temperature of 800° C.; this value may be extended to possibly 900° C. by the use of rather less satisfactory alloys containing 18–20% of chromium and 8–9% of manganese. These steels resist sulphurous gases better than nickel–chromium steels. The advantages of additions of silicon are discussed and it is noted that claims have been made for silicon-bearing chromium–manganese steels which resist scaling up to 1100° C.

**Further Investigations on the Heat-Resistant Properties of Chrome–Manganese Steels. Consideration of the Work of A. M. Borsdyka.** A. N. Gasesyan and B. J. Sheinin. (Kachestvennaya Stal, 1938, vol. 6, No. 2, pp. 45–46; Chem. Abs., 1940, p. 7251). In contrast to the findings of Borsdyka and in agreement with those of Chimuschin and Brühl, studies on chromium-manganese steels containing carbon 0·33–0·47%, silicon 1·02–1·56%, manganese 8·4–11·95%, chromium 14·35–16·70%, and tungsten 2·05–2·50% indicated that steels with 0·33% carbon, 8–10% manganese and 16% chromium do not possess a purely austenite structure but rather a 2-phase austenite-ferrite structure. When these steels are heated to 700° the ferrite decomposes into intermetallic ferrochrome compounds and austenite. This can be demonstrated by microscopic investigation and by the disappearance of the magnetic α phase. Of the steels investigated, a valve steel containing carbon 0·4–0·5%, silicon 1·5–2%, manganese 11–13%, chromium 13–15%, and tungsten 2–2·5 % showed the best mechanical and heat-resistant properties.

**Mechanical Properties and Creep Resistance of Steels for Use in Equipment for Ammonia Synthesis.** N. A. Minkevitch and A. M. Borzdyka. (Kachestvennaya Stal, 1938, vol. 6, No. 1, pp. 8–18; Chem. Abs., 1940, p. 697). Data are given for metallographic characteristics, mechanical properties at normal and high temperatures, creep resistance, and heat resistance of 5 steels for use in equipment for ammonia synthesis. The steels were 2·5%-chromium–molybdenum, 5% chromium–molybdenum, 5% chromium–molybdenum–vanadium, 1·5% chromium–copper, and 2·5% chromium–titanium. The steels were prepared in an acid induction furnace. Grain-sizes (A.S.T.M.) were 4, 5, 8, 3, and 5 respectively. The creep tests lasted up to 48 hr. The highest creep resistance was shown by the chromium–titanium steel. It also had the greatest resistance to scale formation at temperatures up to 538° C. But its impact toughness was rather low at normal temperatures. The 3 chrome–molybdenum steels had rather high and nearly the same creep resistance (stress of 17·4–19 kg./sq. mm. at 400° and 11–11·5 kg./sq. mm. at 500° corresponding to tangential creep of $10^{-6}$ mm./mm./hr. in the interval of 24–48 hr.). At 600° the oxidation of all steels was negligible and at 900° C. the oxidation proceeded intensively.

**Note on Short-Time High-Temperature Tensile Tests of Wrought Nickel–Chromium Alloys.** K. E. Quier. (Metals and Alloys, 1938, vol. 9, pp. 40–44). Tensile strength, reduction of area, elongation and fracture photographs are given for two nickel–chromium alloys: (1) nickel 80%, chromium 20%, and (2) nickel 60%, chromium 16%, iron 24%. Both of the alloys were subjected to short-time high-temperature tensile tests. alloy (1) at 980° and alloy (2) at 875°.

**Heat Characteristics of 5 Silicon–Chromium–Molybdenum Steels.** A. E. White, C. L. Clark, and W. G. Hildorf. (Oil and Gas Journal, 1938, vol. 37, No. 29. pp. 43,46; No. 30, pp. 43, 46, 48).

**The Rupture Strength of Steels at Elevated Temperatures.** A. E. White, C. L. Clark and R. L. Wilson. (Transactions of the American Society for Metals, 1938, vol. 26, pp. 52–69). Long-time rupture tests on two carbon and six alloy steels at temperatures from 538° to 815° C., in which the time for fracture was varied from a few minutes to several thousand hours, showed a definite relationship for each analysis between stress and fracture

time. The tests are a suitable basis for the design of high-temperature apparatus in which some deformation of parts is permissible, and they are the best means for determining ductility properties of steels under the combined action of stress, time, and heating.

**Contribution to the Knowledge of the Austenitic Chromium–Manganese Steels.** H. Legat. (Archiv für das Eisenhüttenwesen, 1938, vol. 11, Jan. pp. 337–341). The mechanical properties and workability of steels with manganese 12–43%, chromium 0–18%, carbon 0·10–1·0% and additions of silicon 0·03–1·0%, nickel 0–4·0%, copper 0–6·0% and molybdenum 0–6·0%, were determined in the forged, annealed, and quenched conditions. In the stable-austenite region the lowest tensile strengths at about 5% of chromium rise with increasing manganese contents ; the yield point reaches a maximum at about 7% of chromium and 33% of manganese. Machinability decreases rapidly with carbon contents above 0·3%.

**Special Steels and Their Application to Engineering and Shipbuilding.** T. Swinden. (North-East Coast Institution of Engineers : Metallurgia, 1938, vol. 17, Mar., pp. 181–185). The author discusses steels employed for engineering and shipbuilding. The properties of various steels at elevated temperatures are dealt with at length.

**Compilation of Available High-Temperature Creep Characteristics of Metals and Alloys.** (Compiled by the Creep Data Section of the Joint Research Committee of the American Society of Mechanical Engineers and the American Society for Testing Materials on Effect of Temperature on the Properties of Metals, 848 pp. Printed in Philadelphia, U.S.A., 1938, Sept.)

**Progress in Stainless and Heat-Resisting Steels.** L. Sanderson. (Engineering and Boiler House Review, 1938, vol. 51, Jan., pp. 458–460). Among the steels referred to by the author are the following : an austenitic steel containing high silicon and tungsten and with a tensile strength of 9 tons per sq. in. at 870° C.; this steel forms a very adherent scale which does not readily flake at 1095° C. and hence contributes to the heat and corrosion resistance of the material ; a steel containing 0·3% of carbon, 0·8% manganese, 1·5% of nickel and 0·12% of vanadium, which is said to be more satisfactory material for furnace-charging boxes than cast carbon steel in so far as it is mechanically stronger and gives increased service life ; a range of heat-resisting steels containing molybdenum, a nickel–chromium steel containing vanadium and molybdenum are also noted ; among other heat-resisting steels the 39% nickel, 10% chromium steels are briefly discussed and reference is made to a steel suitable in the cast form for power-plant fittings operating at high temperatures ; its composition is nickel 2·05%, chromium 0·8%, carbon 0·35%.

**Comparison of the Tensile Deformation Characteristics of Alloys at Elevated Temperatures.** C. R. Austin and H. D. Nickol. (Journal of the Iron and Steel Inst., 1938, No. 1, pp. 177–201P). Part I presents details of a new type of equipment for the comparative study of stress/deformation/time relationships of alloys at elevated temperatures. The behaviour of seventeen alloys at 600°, 700°, and 800° C. under stresses ranging from 2000 to 8000 lb. per sq. in. is indicated by tabulated data and by deformation-time curves arranged to illustrate the three classes of alloys studied :

(1) Austenitic stainless 18/8 steels.
(2) Ferritic chromium–iron alloys.
(3) Konel-type alloys—K42B and modifications.

A few data are also included relating to resistance to deformation at 1000° C. and at 950° C. in a hydrogen atmosphere. Part II provides a metallographic study of the effect of temperature and stress on stainless 18/8 steels, chromium irons, and Konel-type alloys. Details of the preparation of the samples and of the etching technique are described.

**Selection of Steels for High Temperatures.** M. Fleishmann. (Steel, 1938, vol. 102, Jan. 17, pp. 34–39). The author considers the mechanical properties of steels at high temperatures and the effect upon these properties of the corrosion- and scale-resistance of the material. In particular creep strength is discussed. Specimens are stressed at various loads until fracture occurs ; the loads causing rupture are then plotted on logarithmic co-ordinates against the time which elapses before the specimen breaks. Curves obtained in this way are apparently straight lines and extrapolation is possible to time periods equivalent to the commercial life desired. Curves obtained for Timken 4/6 chromium–molybdenum steel and for " Sicromo 5 " are discussed ; breaks in the curve for the first material are apparently due to oxidation increasing with prolonged heating. The influence of various additions of chromium, molybdenum, silicon, aluminium, titanium, and niobium on the corrosion-or scale-resisting properties of steels is discussed and the effect of varying the carbon contents is considered. The influence of the microstructure and of mechanical working is dealt with. Reference is made to engineering problems in the oil industry. Data are presented in graphical form.

**Determination of the Heat-Resistance during Creep Tests at Below and Above the Recrystallisation Point.** E. Both and W. Rohn. (Deutsche Gesellschaft für Metallkunde, General Meeting, 1938, June. pp. 16–22). The authors describe the apparatus used for determining the creep of metals. They found that as the temperature fell from below the recrystallization point, the elongation was reduced, but at a decreasing rate, but when the initial temperature was above the recrystallization point, the elongation decreased at an increasing rate.

**High-Nickel Nickel–Chromium–Iron Alloys for Furnace Work.** (Nickel Bulletin, 1938, vol. 11, Dec., pp. 257–261). The properties of nickel–chromium-iron alloys are presented and the application of these alloys for the construction of heat-treatment furnaces is discussed.

**Steel for Aircraft Engine Valves.** M. V. Pridantsev and E. Z. Klausting. (Kachestvennaya Stal, 1938, No. 1, pp. 18–24). The properties of a steel containing carbon 0·45%, chromium 17·36%, nickel 6·5%, silicon 0·4% and manganese 0·4% were studied from the point of view of its application for aircraft-engine valves.

**Corrosion and Heat Resisting Steels.** W. H. Hatfield. (Metallurgia, 1938, vol. 19, Dec., pp. 59–61). The author discusses the advance in the technology of corrosion- and heat-resisting steels under four headings : (*a*) the development of improved or new compositions ; (*b*) the improvements in production as regards forms, sizes, and quality ; (*c*) the increasing knowledge of the various methods of manipulation and fabrication of the steels in all forms into plant of every description ; and (*d*) the ever-widening application of these steels throughout all industries.

**Notes on Etching Inoxidizable Steels.** J. A. Vero. (Publications of the Department of Mining and Metallurgy of the Royal Hungarian Palatine-Joseph University of Technical and Economic Sciences, 1938, vol. 10, Part I, pp. 183–190). The author gives an account of his investigation of reagents suitable for etching austenitic acid- and heat-resisting steels. The two most suitable methods found were : (*a*) Anodic etching in 10% oxalic acid, and (*b*) the use of an alcoholic hydrochloric-acid/cupric-chloride solution. The former is very useful for austenitic steels containing a high percentage of chromium, and

the latter can be used for ferritic and martensitic steels and those containing less than 15% chromium.

**Steels for Petrol-Producing Plants.** F. K. Naumann. (Technische Mitteilungen Krupp, Technische Berichte, 1938, vol. 6, Aug. pp. 77–87). The author considers the qualities of steels which are required in the construction of plants for the three processes of producing petrol, namely, by cracking, by hydrogenation (the Bergius process) and by synthesis from water-gas (the Fischer-Tropsch process). The discussion is confined principally to steels for the second process as its conditions are the most exacting. In this the steels are required to resist the attack of hydrogen and of sulphuretted hydrogen at pressures of from 300 to 700 atm. and at temperatures of from 450° to 550° C. The author shows by graphs the results of many tests made to investigate the effect of various percentages of chromium, nickel, molybdenum, silicon, and aluminium in the steel on the rate of corrosion when subjected to attack by these gases.

**Valve and Valve Seat Technique.** F. R. Banks. (Journal of the Institution of Automobile Engineers, 1938, Dec., vol. 7, pp. 32–59). Part 1. (Automobile Engines). Reference is made to the development in the U.S.A., of modified Silchrome steels containing up to 5% of nickel (Silchrome XCR and XB). The properties of the various grades are given. The austenitic type of steel now used in England is D.T.D. 49B (Carbon 0·35–0·45%, nickel 12·5–14·5%, chromium 12·5–14·5%, tungsten 2·0–3·0%). This steel has good strength properties at service temperatures, and is highly resistant to oxidation and corrosion attack at all temperatures. Where heavy duty is required from the engine, such valves give very satisfactory performance in conjunction with Stellite seats. When austenitic steel valves are used the valve stem should be provided with a hardened tip. Among the materials used for the latter purpose is a nickel–chromium steel (carbon 0·35–0·45%, nickel 1·0–1·5%, chromium 0·45–0·75% which is specially popular for 'bus and lorry engine valve-stem tips. For valve inserts in aluminium cylinder heads, the steels used are generally of the high expansion type, *e.g.*, N.M.C. (nickel 12%, manganese 5%, chromium 3·5%, carbon 0·5–0·6%), or an austenitic steel of the D.T.D. 49B class. Part 2 (Aero Engines). The essential differences between the conditions dictating choice of valve design and material (*a*) in automobiles. (*b*) in aircraft are discussed and particulars are given of current British and American practice.

**Special Steels for the Petroleum Industry.** (Petroleum Times, 1938, Aug. 6, p. 183). A statistical survey carried out by the Brymbo Steel Co. Ltd., revealed some remarkable figures. Evolution of special steels has resulted from the modification of the chromium content of the original stainless steel and the addition of special elements in varying proportions. The heat-resistant steels fall into four groups: plain chromium steels containing 12–30% of chromium, silicon–chromium steels, austenitic chromium–nickel steels containing chromium and nickel each up to 30% with or without additions of tungsten and titanium, and higher nickel–chromium alloys, such as 60% of nickel and 20% of chromium.

**Estimating Life of Electrical Heating Elements.** F. E. Bash. (Metal Progress, 1938, vol. 33, Feb., pp. 143–147). Discussion of effect of wire cross-section; description of testing methods at Driver-Harris Co.

**Electrical Heating Element for High Temperatures.** W. Trinks. (Industrial Heating, 1938, vol. 5, Jan., pp. 74–76). Describes tests on a heating element developed in Austria which, it is claimed, will withstand temperatures up to about 1500° C. Element consists of a molybdenum resistor encased first in a layer of metallic oxides (chiefly beryllium oxide) and then in an outer coating of a suitable ceramic material.

**Development in the Use of Petroleum Derivatives.** G. Egloff. (Petroleum Times, June 4, 1938, p. 735). A great advance in alloy steels was accomplished by the addition of 0·5% of molybdenum plus 1% to 5% of chromium. Chromium is kept from combining with the carbon present in steel by the addition of stable-carbide-forming elements such as titanium and columbium, which make the alloy resistant over a wide range of corrosion conditions. Addition of titanium, silicon, and aluminium, by themselves, or in combination, has imparted to pearlitic steels high oxidation-resistant properties that, within a wide range of temperatures, are as good as those attributed to austenitic steels alone. In the manufacture of reaction chambers, addition of 1% of molybdenum to low-carbon steel practically doubles the strength of these vessels at temperatures of 475° C. and above.

**Mechanical Properties of Heat-Resistant Steels with 25% Nickel, 21% Chromium and with 30% Chromium at Elevated Temperatures.** N. Pik. (Teoriya i Practika Metallorgiya, 1938, vol. 10, No. 2, pp. 68–74 : Metals and Alloys, August, 1938, p. MA 510). Tensile strength, impact strength, and dynamic compression of steels containing 0·23% of carbon, 0·9% of silicon, 0·6% of manganese, 25·0% of nickel, 21·0 % of chromium and 0·15% of carbon, 0·9% of silicon, 0·3% of manganese, 30·3% of chromium were investigated in the 500–1200° C. range. The tensile strength of the second rapidly drops on heating to 800° C. and drops gradually above this temperature, becoming 300 lb./sq. in. at 1200° C. Impact strength increases continuously. Elongation increases rapidly to 1000° C. and more slowly afterwards, reaching a maximum of 71% at 1200° C. The first steel rapidly loses strength up to 1100° C. and more slowly above this temperature, but is much stronger than the second. Elongation reaches a maximum of 39% at 1100° C. and then decreases, depending to some extent on the time at the temperature. Extensive data are presented, including 14 diagrams.

**Materials for High Pressure High Temperature Steam Service.** G. Chadwick. (Journal of the American Society of Naval Engineers, 1938, vol. 50 (1), pp. 52–84). Data are given for 30 alloys, mainly alloy steels, but including a nickel–chromium alloy containing nickel 78%, chromium 1%, iron 8%. These data include composition, physical properties up to 535° C., and fabrication properties.

**The Manufacture of Nickel-Chromium Resistance Wire.** F. P. Peters. (Metals and Alloys, 1938, vol. 9, Oct., pp. 263–269). Manufacture of nickel–chromium resistance alloys constitutes one of the most intricate of metallurgical problems. Successful production of a heating-element wire which will give long life at high temperature depends largely on starting with a clean, sound, workable ingot of the desired grain-size. Melting is complicated by the high vapour pressure and oxidizability of chromium and the affinity of nickel for hydrogen and sulphur. Additions of grain-refining and "protective" elements must be carefully controlled, in order to preserve cleanliness, workability, and long-life qualities. Time and temperature are other important factors in the melting process. Strict control is also necessary in all subsequent production stages, *viz.*, reheating, rolling, annealing, pickling, and drawing.

**Thermal Expansion and Effects of Heat Treatments on Growth, Density and Structure of Some Heat-Resisting Alloys.** P. Hidnert. (Journal of Research of the National Bureau of Standards, 1938, vol. 20, June, pp. 809–824). Coefficients of linear expansion for various temperature ranges between 20° and 1000° C. were obtained on some new heat-resisting alloys (Fe 53·1%, Cr 38·6%, Al 7·9%); and three Kanthal alloys (containing iron, chromium, aluminium, and cobalt).

**Scaling and Change with Time of the Resistance of Some Alloys for Heating Elements.** F. Mertens. (Electrowärme, 1938, No. 8, pp. 3–4 : Chem Abs., 1938, p. 2887). In taking the increase in weight after 800 hours of annealing as indicative of the life of a heating element, the increase was found least in chromium–iron–aluminium alloys; then follow chromium–nickel alloys, chromium–nickel–iron alloys, chromium–nickel with high nickel content, chromium–iron–silicon and lastly nickel-poor chromium–nickel alloy. The good result of the chromium–iron–aluminium alloy is due to the formation of a very dense, firmly adhering layer of aluminium oxide which prevents further oxidation. The resistance of these alloys decreases about 3% after 800 hr. while the others show increases from 3 to 20%.

**Typical Failures of Still Tubes in Refineries.** E. C. Wright. (Metal Progress, 1938, vol. 34, Nov., pp. 573–578). The author summarizes the results of a number of metallurgical examinations undertaken to establish the causes of failures in oil-refinery still tubes. He finds that in practically all cases the original carbide as pearlite had been changed to the spheroidized state, the only difference between the various fractures being in the size of the carbide particles.

**Manganese Steel for Boiler Construction.** Ya. S. Gintsburg, E. A. Podisebenko, and M. S. Freydel. (Kachestvennaya Stal, 1938, No. 3, pp. 9–14). An investigation was made of the mechanical properties at normal and elevated temperatures, the tendency to age, the embrittlement and the creep strength of 1·3–1·5% manganese steel. As regards its tendency to age, the steel occupies an intermediate position between ordinary carbon steel and non-ageing steel, whilst all its other properties render it entirely suitable for boiler construction.

**Electric Heat Treatment of Chromium–Molybdenum Steel Tubes.** F. Vdovin. (Stahl, 1938, No. 5, pp. 48–54). Working with steel containing 0·85% of chromium, 0·22% of molybdenum and 0·30% of carbon, the author, after developing suitable equipment, studied the possibility of normalizing cold-drawn tubes using the heat generated by the passage through them of a sufficiently strong electric current which was supplied from a step-down transformer. The effects of different combinations of current value, time and temperature, (up to 950°C.) on the mechanical properties and microstructure are reported.

**Effect of Temperature Variation on the Creep Strength of Steels.** E. L. Robinson. (Transactions of the American Society of Mechanical Engineers, 1938, vol. 60, pp. 253–259). The author explains, with examples, the application of some formulæ for calculating the effect of temperature fluctuations on the creep rate for steels at elevated temperatures.

**Creep of Metals at High Temperatures in Bending.** E. A. Davis. (Transactions of the American Society of Mechanical Engineers, 1938, vol. 60, pp. A29–A31). The author develops a theory for plastic bending and obtains equations for calculating the creep resulting from bending. He also describes some tension and bend tests conducted at 816° and 900° C. on specimens of a chromium–nickel steel the results of which supported his theory.

**Corrosion and Heat Resisting Steels—Pts. I–VI.** W. H. Hatfield. (Silk and Rayon, 1938, Jan.–June). In Parts I and II the various types of steel resistant to corrosion and heat are discussed in general terms. Part III discusses the mechanical and physical properties and resistance to scaling and creep. Part IV relates to the forms in which the steel is available whilst V and VI deal with manipulation.

**Heat-Resistant Steel Alloys for High-Pressure Steam Plants.** P. Grün. (Polytechnisch Weekblad, 1938, vol. 32, pp. 358–360 : Chemisches Zentralblatt, 1939, I, p. 1439). The high pressures with temperatures up to 550° C. used in boilers and turbines in the last 10 years require special testing methods, which are described in detail. Some alloy steels for use at temperatures of 400–550° C. are described and data on their heat-resistant properties are given.

**Effect of Repeated Cold-Working on the Properties of Heat-Resisting Chromium–Molybdenum and Nickel–Chromium–Molybdenum Steels.** E. Greulich and H. Zschokke. (Archiv für das Eisenhüttenwesen, 1938, vol. 11, pp. 401–404). In heat-resisting steels of 0·5% carbon, 1·3% chromium, and 0·6% molybdenum, and of 0·15% carbon, 1·5% nickel, 0·75% chromium and 0·8% molybdenum, repeated cold deformation with intermediate annealing decreases the temperature range for soft-annealing and deteriorates the mechanical properties ; this is ascribed to the easier transformation of streaky pearlite into granular cementite. Creep strength in the soft condition after such repeated cold deformations is considerably lower than in the hot-rolled and refined condition, but can be restored to a large extent again by a final heat-treatment. A heat-treatment at 500–550° produced higher creep strength than annealing above 550°.

**Influence of Heat-Treatment on Creep of Carbon–Molybdenum and Chromium–Molybdenum–Silicon Steel.** R. F. Miller, R. F. Campbell, R. H. Aborn, and E. C. Wright. (Transactions of the American Society for Metals, 1938, vol. 26, pp. 81–101 : Chem. Abs., 1938, p. 3741). (1) A 0·21% carbon, 0·54% molybdenum and (2) a 0·20% carbon, 1·56% chromium, 0·65% molybdenum, 0·49% silicon steel were tested for 3000 hr. up to 593°C. For (1) the most creep-resistant structure contains a fine shower precipitate. Structural stability accompanies a constant creep rate. Specimens showing the greatest change of structure also show the greatest tendency for an increasing creep rate. For (2) little change of structure occurs during the tests, except at 593° C. where carbide coarsening occurred. At 593°C. the annealed material was superior to the normalized and tempered material.

**Heat Resisting Alloys for the Exhaust-Gas Turbine.** F. Bollenrath, H. Cornelius, and W. Bungardt. (Metal Treatment, 1938, vol. 4, Winter issue, pp. 182–187). An English translation of a report published in Metallwirtschaft, 1938, vol. 7, July 15, pp. 755–757.

**The Embrittlement of Heat-Resisting Steels at High Temperatures.** R. Scherer and H. Kiessler. (Archiv für das Eisenhüttenwesen, 1939, vol. 12, Feb., pp. 381–385). The authors have examined the causes of the fracture of bolts used at the joints of high-temperature pipe-lines by carrying out fatigue tests on notched bars up to fracture and examining the fractured bars under the microscope. They come to the following general conclusions : (1) Nickel-bearing steels tend to be hot short, whereas chromium–molybdenum steels do not ; (2) the cause of fracture at 500–600° C. without deformation is a general brittleness across the section accompanied by local stress concentrations ; (3) hot-shortness is accompanied by a strengthening of the grain boundaries ; (4) hot-shortness is a similar phenomenon to temper-brittleness, but has no connection with strain-ageing ; and (5) hot-shortness will not occur in a steel containing no nickel, the composition of which is selected so as to suppress as far as possible any change of structure at the grain boundaries at the working temperature.

**Embrittlement of Creep-Resisting Steels at High Temperatures.** (Metallurgist, 1939, vol. 12, June, pp. 46–48). An abridged English translation of the above paper. The conclusions of these authors are discussed and compared with those of other investigators.

**Application of Steel to Operations at High Temperature.** T. M. Jasper. (Metal Progress, 1939, vol. 35, Feb., pp. 160–163). The author comments on the variation in the results of tests made to determine the ultimate strength and the yield point of steels at elevated temperatures, and describes the methods he uses to obtain data concerning steel for plant which is to operate at up to 538°C. One method is to take several specimens of the steel, and, at a definite temperature, load each to a constant stress until either failure occurs or the load is maintained for a very long time without failure. The times taken for failure to occur and the test stresses for each specimen are plotted; the value of stress obtained from that portion of the curve parallel to the time axis represents the stress that the steel can carry for an indefinite period of time. To determine the ultimate yield point a number of specimens of the steel are subjected to increasing loads at the same temperature but at different rates of load increment, and their limits of proportionality are plotted against the time intervals at which the loads are increased; the constant value which this curve approaches is sometimes called "the long-time limit of proportionality." This curve shows that the limit of proportionality is higher for the more rapid rates of loading, and approaches a constant value as the time between load increments is increased.

**The Mechanical Properties at High Temperatures of the Rustless Corrosion- and Heat-Resisting Steels.** A. Farnik and St. Kulinski. (Prace Badawcze Huty Baildon, 1939, No. 5, Feb., pp. 65–74). The authors describe the corrosion- and heat-resisting steels manufactured in Poland, and investigate the influence of alloying elements on the properties of such steels. They come to the following conclusions: Steels containing high percentages of chromium with and without nickel have better mechanical properties than those with only small additions of non-ferrous metals; the addition of 2% of molybdenum to the 18/8 steels produces a marked improvement in their properties; the addition of about 1·5% of titanium to a molybdenum-bearing steel is beneficial, and the two elements increase the creep limit, especially at temperatures up to 600°C.; steels containing nickel 18% and chromium 25% have excellent mechanical properties and low coefficients of expansion.

**The Composition of Plates for Tanks, High-Pressure Boilers and Autoclaves, and Their Resistance to Temperatures in the Range 20–600° C.** I. Feszczenko-Czopiwski, W. Koss and J. Glatman. (Prace Badawcze Huty Baildon, 1939, Feb., No. 5, pp. 51–63). The authors examine the effect of additions of alloying elements on the properties of steel with special reference to creep resistance, and present several tables and graphs showing the composition and mechanical properties of many steels used for high-pressure steam boilers. Their conclusions are as follows: (1) Low-alloy steels not containing molybdenum have not very good heat-resisting properties; (2) the addition of 0·20–0·30% of molybdenum increases the tensile strength at high temperatures of steels containing 0·20–0·25% of carbon to a marked degree, especially when 1% of chromium is also present; (3) the addition of 0·5–0·6% of molybdenum to a 0·1% carbon steel does not further improve its heat-resisting properties; and (4) the addition of copper instead of chromium lowers the heat-resistance of steel in the temperature range of 300–600° C.

**The Effect of Nitrogen Additions and Heat-Treatment on the Properties of High-Chromium Steels.** E. W. Colbeck and R. P. Garner. (Journal of the Iron and Steel Institute, 1939, No. 1, pp. 99P–136P.). Experiments have been carried out on the heat-resisting properties of 23–28% chromium steels, and it has been found that nitrogen additions are valuable in inhibiting grain growth at 1100° C. and in preventing embrittlement after exposure to such conditions. During the course of the investigation it was repeatedly observed that addition of nitrogen followed by the correct heat-treatment improved the machinability of these high-chromium steels.

**Selective Tests on High-Temperature Heat-Resisting Steels.** N. Minkevich and A. M. Borzdyka. (Metallurg, 1939, No. 1, pp. 61–78). The following groups of steels were tested with a view to selecting suitable alloys for service at 800–1000° C.

I. Austenitic chromium–nickel base steels.

| | C | Si | Mn | Ni | Cr | W | Mo |
|---|---|---|---|---|---|---|---|
| Steel (*a*) % | 0·55 | 0·75 | 0·64 | 15·1 | 14·2 | 2·4 | 0·41 |
| Steel (*b*) % | 0·40 | 1·50 | 0·50 | 13·0 | 12·9 | 11·2 | — |

II. Austenitic, or nearly austenitic, chromium–manganese base steels.

| | C | Si | Mn | Cr | W | Ti |
|---|---|---|---|---|---|---|
| Steel (*c*) % | 0·38 | 1·8 | 12·2 | 14·7 | 2·2 | — |
| Steel (*d*) % | 0·41 | 1·65 | 13·6 | 14·1 | 3·1 | — |
| Steel (*e*) % | 0·51 | 2·3 | 15·2 | 13·8 | — | 2·6 |

III. Pearlitic, carbide-bearing, chromium-base steels.

| | C | Si | Mn | Cr | W | V | Mo |
|---|---|---|---|---|---|---|---|
| Steel (*f*) % | 0·47 | 1·8 | 0·5 | 9·2 | 3–4 | 0·75 | — |
| Steel (*g*) % | 0·50 | 1·4 | 0·5 | 8·6 | — | — | 2·25 |

The behaviour of these steels at elevated temperatures was first studied by dilatometric and hardness measurements and under the microscope, and the structural changes which occured are discussed. These preliminary experiments were followed by scaling tests, short-time tensile tests at 20°, 800° and 1000° C., impact tests at the same temperatures, tests on the development of brittleness on heating at 600° and 800° C. for up to 120 hr., and, finally, by creep tests at 800° and 900° C. ($10^{-4}$% elongation/hr. between the twenty-fourth and forty-eighth hours.) The results of the short-time tensile tests and the creep tests enable the steels to be divided into two groups: those resistant to high temperatures and those resistant to low temperatures. Steels (*a*), (*b*), (*c*), and (*d*) were found to belong to the former, and steels (*c*), (*f*), and (*g*) to the latter group. Steels of the first group differ but slightly among themselves, steels (*a*) and (*c*) being the best. At 800° C. the steels of the first group differ from those of the second much more in short-time tensile strength (differences of 200–250%) than in creep strength (differences of 25–35%). These differences were much less at 900–1000° C. Steel (*e*) was shown by all the tests to have the lowest heat-resistance.

**The Creep of Metals.** D. Hanson. (American Institute of Mining and Metallurgy, Technical Publication No. 1071: Metals Technology, 1939, vol. 6, June). In the first part of this paper, the author studies the factors influencing the creep of metals and the relation between them, and in the second part he considers the metallographic aspect of creep. Referring to the fact that very different results are often obtained by different investigators of creep when using similar materials, the author believes that this is an indication of the fact that the creep characteristics of a metal are influenced profoundly by factors that are comparatively unimportant in relation to mechanical properties at low temperatures.

**Heat and Corrosion-Resistant Castings of the Chromium–Nickel–Iron Types.** J. D. Corfield. (American Foundrymen's Association, 1939, May, Preprint No. 30). The author surveys from the foundryman's point of

view the properties of heat- and corrosion-resisting cast irons containing nickel and chromium.

**The Alloy Casting Research Institute Test-Block for Heat-Resisting Alloys. Its History, Selection, and Utilization.** O. E. Harder. (Proceedings of the American Society for Testing Materials, 1939, vol. 39, pp. 626–636). A survey conducted to determine the most suitable type of test-specimens of heat-resisting alloys for the determination of tensile strength and creep characteristics at high temperatures. A wedge-shaped test-block with a riser along the entire length but gated only at the bottom has been developed.

**The Rôle of Heat-Resisting Alloys in Short-Cycle Malleabilizing Furnaces.** H. H. Harris. (Transactions of the American Foundrymen's Association, 1939, vol. 46, June, pp. 832–849). The author discusses the design of rails, rollers, bearings, and trays used in the construction of short-cycle malleabilizing furnaces.

**Is There a True Creep Limit ?** U. Dehlinger. (Zeitschrift für Metallkunde, 1939, vol. 31, June, pp. 187–191). The true creep limit is defined as the constant creep limit still observed after a very long duration. The author develops an equation which leads to an understanding of the different creep properties of amorphous, single- and poly-crystalline substances. He shows that the value of the creep limit for single crystals is zero and that there is no true creep limit for amorphous substances. There is a true creep limit, however, for polycrystalline materials, which is, at least for coarse-grained materials, identical with the fatigue limit.

**The Strength of Metals at Elevated Temperatures.** R. F. Miller. (Mechanical Engineering, 1939, vol. 61, Aug., pp. 589–594). The author describes methods for determining the rate of creep at different temperatures and reproduces graphs showing the percentage elongation in relation to time. There are two recognized methods of relating stress to creep in the United States ; one is to determine the stress which will produce a creep rate of 1% per 10,000 hr., and the other is to determine the stress which will produce a creep rate of 1% per 100,000 hr. The latter is used when designing parts for steam turbines, in which the amount of creep must be exceedingly small.

**Alternating-Current-Bridge Thermostat for Creep Testing.** L. E. Prosser. (Engineering, 1939, vol. 139, July 28, pp. 95–96). A new thermostat is described which has been developed for controlling the high-sensitivity creep-testing furnaces in the Engineering Department of the National Physical Laboratory.

**The Behaviour of Steels at High Temperatures.** C. A. Duckwitz. (Berg- und Hüttenmännische Monatshefte der Montanistischen Hochschule in Leoben, 1939, vol. 87, May, pp. 97–105). The author discusses a number of methods of determining the strength of steel at high temperatures.

**Fracture of Steels at Elevated Temperatures after Prolonged Loading.** R. H. Thielemann and E. R. Parker. (American Institute of Mining and Metallurgy, Technical Publication No. 1034 : Metals Technology, 1939, vol 6, Apr.). The authors describe the testing technique developed at the research laboratories of the General Electric Co. for carrying out sustained-load rupture tests on steel specimens at high temperatures. They found that two distinct types of fracture occur, the transcrystalline and the intergranular. In the former, the break occurs through the grains and in the latter, through the grain boundaries. The authors present the result of numerous tests in tables, graphs, and micrographs.

**New Researches in Steel Metallurgy.** W. H. Hatfield. (Royal Institution, Mar. 17, 1939). The author shows that research in steel metallurgy is directed in the main to three principal aspects : (*a*) Elucidation and improvement of the processes of steel manufacture and manipulation, (*b*) the investigation of the properties of steel under variable conditions approximating to those of service, and (*c*) the exploration of the influence of added elements and of the effect of heat-treatment in advantageously modifying the properties of steel. The author discusses some of the results which have been obtained in these directions. In investigating creep properties the usefulness of a short-time test was obvious and he describes a three-day test which has been developed and is being used on an extensive scale in the testing of many alloy steels. In this test the applied stress produces deformation not exceeding 0·5% of the gauge length in the first 24 hr., but during the next 48 hr. no further change in dimensions takes place within the accuracy of measurement, which is to 0·0004 inches. On a gauge length of 2 inches this is approximately equivalent to one-millionth of an inch per inch per hour. The maximum stress not producing a de-deformation in excess of that so postulated has been named the "time yield." The determination of the "time yield" enables many steels to be compared as to behaviour at different temperatures.

**Creep Strength Tests while Recording Time-Stress Curves.** K. Wellinger. (Archiv für das Eisenhüttenwesen, 1939, vol. 12, May, pp. 543-550). The author describes a method of creep testing which was developed at the Stuttgart Material Testing Laboratory. This was a method in which the first two of the three variables temperature, strain, and stress were kept constant when testing different specimens and the different stresses required to produce the same strain in the different specimens were measured and compared. A 50-ton tensile-testing machine was used and a recording device controlled by a very delicate vacuum-enclosed switch enabled stress-time curves to be obtained as the tests proceeded. He presents and discusses the results obtained with this machine on a number of alloy steels.

**The Influence of Small Alloying Additions on the Scaling and Decarburisation of Steel.** H. Schrader. (Stahl und Eisen, 1939, vol. 59, Apr. 20, pp. 473–482). A survey of the work of several investigators is presented by the author on the effects which small additions of a number of alloying elements have upon the scaling and decarburization of steel. The alloying elements used were aluminium, beryllium, boron, chromium, cobalt, copper, nickel, manganese, molybdenum, phosphorus, silicon, tin, titanium, and tungsten, and the investigations were carried out on specimens annealed for different times, at different temperatures, and in different atmospheres. The scaling tests produced results which were in close agreement, but the results of surface-decarburization tests were frequently contradictory. The author gives possible explanations for the conflicting results.

**The Influence of Alloying Elements on the Scaling and Decarburisation of Steel.** (Metallurgist, 1939, vol. 12, Oct., pp. 73–75). It is pointed out that a comparison of the scaling properties of any two steels should always be made with reference to the same temperature and the same oxidizing atmosphere. With these limitations in mind the results of H. Schrader's experiments are discussed.

**The Melting of Heat-Resisting Steels for Casting in a Basic Open-Hearth Furnace.** M. Kolosov and N. Keys. (Stal, 1939, No. 7, pp. 19–20). Brief details of the process used for melting four 6-ton heats of heat-resisting steel (carbon 0·13–0·14%, silicon 1·74–3·02%, manganese 0·78–1·10%, chromium 2·91–4·13%, molybdenum 0·40–0·42%, aluminium 0·2–0·4%) in a 7-ton oil-fired open-hearth furnace. The temperature of the tapped

metal was 1510–1530° C. and it was poured from a fire-clay-lined ladle (diameter of opening 45 mm.) with a magnesite stopper. The steels from the various heats were cast into 100-kg. billets which were used in a sheet-normalizing furnace at temperatures of 850–1050° C. in contact with the products of combustion.

**Heat-Resisting Alloys.** W. H. Hatfield. (Journal of the Birmingham Metallurgical Society, 1939, vol. 19, Dec., pp. 155–163). In this general outline of the properties of heat-resisting steels, the author presents some tables of the analyses, scale-formation and strength properties of these alloys and describes some long-time creep tests of an unusual nature which are being conducted at Sheffield.

**The Weldability of Heat-Resisting Steels.** (Welding Industry, 1940, vol. 8, Feb., pp. 15–19). Reference is made to the heat-resisting properties and applications of six types of "Era H.R." steel which are claimed to resist scaling at temperatures up to 1150° C.

**Method of Determining the Limiting Deformation and the Limiting Stress in Creep.** I. A. Oding. (Zavodskaya Laboratoriya, 1939, No. 8, pp. 856–859). Limiting deformation is defined as the deformation undergone by a specimen up to the commencement of necking, which sets in when the intensity of work-hardening becomes equal to the loss in strength as a result of the reduction in cross-sectional area. Both the limiting deformation and the limiting stress can be obtained graphically from the stress-elongation diagram, and this enables the approximate life of the material for a given stress and creep rate to be determined, provided that the material does not undergo structural changes at the temperatures involved.

**Some Things We Don't Know about the Creep of Metals.** H. W. Gillett. (American Institute of Mining and Metallurgy, Technical Publication No. 1087: Metals Technology, 1939, vol. 6, Aug.). In discussing several examples of time-elongation curves, the author divides these into three phases; the initial phase in which the creep rate rises rapidly and then falls off to the beginning of the second phase, which represents a long period at a constant rate, and the final stage which is usually extrapolated. He deals with the effects of grain-size, alloying elements, stability at high temperatures, precipitation-hardening and embrittlement on creep rates. He discusses both graphical and mathematical extrapolation and refers to the efforts which have been made to establish mathematical functions for strain-hardening, annealing, spheroidization and precipitation-hardening effects and to combine them all into a formula that will express the future course of a creep curve for ten or twenty years, but considers that such efforts are of little value. In his opinion it is necessary to persevere with endeavours to obtain more data by painstaking research. A bibliography of ninety-four references to the literature on creep is appended.

**On the Creep of Alloy Steels at High Temperatures.** H. Krainer. (Zeitschrift für Metallkunde, 1939, vol. 31, July, pp. 239–240). In this mathematical discussion the author considers some equations for calculating the creep rate of steels and he presents a table showing creep data for fifteen alloy steels in various ranges of temperatures.

**Report on Torsion Creep Tests for Comparison with Tension Creep Tests on a Carbon-Molybdenum Steel.** F. L. Everett and C. L. Clark. (Proceedings of the American Society for Testing Materials, 1939, vol. 39, pp. 215–224). Steel containing 0·53% of molybdenum and 0·14% of carbon was tested at four creep rates in torsion and in tension. At 566° C. the ratios of torsional creep strength to tension were about 0·8 and 0·6 respectively, for strain rates of 0·01% and 0·1%/1000 hr. at 1000 hr. At 427° C. the ratio was about 0·6 for both rates of creep. Theory and experimental results are discussed.

**Creep in Tubular Pressure Vessels.** F. H. Norton. (Transactions of the American Society of Mechanical Engineers, 1939, vol. 61, pp. 239–245). The paper is a report of tests on circumferential and longitudinal creep under internal pressure and high temperature, in steel tubes such as are used in boilers and oil stills. A description of the testing apparatus is given and the results are shown in the form of tables and curves comparing tubular creep with the creep of tensile specimens at the same stress. A tentative conclusion is reached that circumferential creep is about half that of tensile specimens. The longitudinal creep is negligible.

**Correlation of Test Results for Various Types of High-Temperature Tests Carried out for the A.S.M.E.-A.S.T.M. Joint Research Committee.** E. A. Davis. (Proceedings of the American Society for Testing Materials, 1939, vol. 39, pp. 234–237). The results of Everett and Clark and of Norton are correlated. The author uses Nadai's transformation equations and compares the octahedral shearing stress with the shearing strain rate in the plane in which this stress acts. The agreement at 427° C is fair, while at 566° C. there is a considerable scattering. Norton's steel may have been of smaller grain-size. It showed the more rapid creep rates at 566° C.

**Creep of Some Chromium-Molybdenum Steels.** H. D. Newell. (Metals and Alloys, 1939, vol. 10, pp. 342–345). The high-temperature creep properties of 5% chromium steels containing 1 to 1·5% molybdenum were investigated to determine whether the increased molybdenum content provides any improvement over the common approximately 0·5% molybdenum alloy. Silicon was somewhat increased also, to increase the oxidation resistance. The results indicate that while the higher percentage molybdenum steels have slightly better resistance to creep throughout the temperature range studied, 538° to 649° C., there is not sufficient difference in stress values to justify the increased cost of the addition over the usual 0·5% molybdenum addition.

**The Resistance to Relaxation of Materials at High Temperature.** E. L. Robinson. (Transactions of the American Society of Mechanical Engineers, 1939, vol. 61, pp. 543–550). After a discussion of the general characteristics of relaxation tests which have been previously described (see p. 26), the author presents several series of graphs which illustrate the trend of the results of numerous relaxation tests at 399° and 454° C. on bars and tubes of S.A.E. 4140 steel and of molybdenum and chromium–molybdenum steel.

**Effect of High Temperatures and Pressures on Cast Steel Venturi Tubes.** W. S. Pardoe. (Transactions of the American Society of Mechanical Engineers, 1939, vol. 61, pp. 247–248). The author presents the results of tests of the expansion in the main and throat diameters of cast-steel venturi tubes subjected to dry heat and to pressure. From these data he calculates the coefficient of expansion and the modulus of elasticity.

**High-Temperature-Steam Experience at Detroit.** R. M. van Duzer, jun., and A. McCutchan. (Transactions of the American Society of Mechanical Engineers, 1939, vol. 61, pp. 383–398). The authors report on an examination of certain parts of the 10,000-kW. steam turbine which was erected in 1933, and dismantled in 1937 after over 26,000 hr. of service most of which was with steam at 538°C. A study of the principal materials used in its construction, as well as for the tubing and superheater, showed that, with some exceptions, the alloy steels used were in good condition, and that the amount of creep had been very small.

**Effect of the Composition on the Creep Properties of Carbon Steel.** A. Simizu. (Transactions of the Society of Mechanical Engineers of Japan, 1939, vol. 5, No. 21, I, pp. 136–139 : Chem. Abs., 1941, p. 4331). The effect of the carbon content was investigated by the torsion creep test with 6 kinds of steel at 450°. All the creep angles and the other creep characteristics, determined in the investigation of the torsion creep, decrease generally as the carbon content increases. Up to the content of 0·45% the decrease occurs rather sharply, but for higher content it occurs gradually. The resistance to the deformation increases suddenly from 0·45% by the combined effect of the increase of the pearlite portion and the fineness of the grain. The empirical formula for the relation between the creep angle and the carbon content was determined.

**New Developments in Steels for Oil Refinery Service.** M. Fleishmann. (Oil and Gas Journal, vol. 37, Mar. 30, 1939, pp. 94, 96, 129, 132, 136, 138). The range of chromium steels of from 5% to 10% of chromium with 0·5–2% of silicon and up to 1·1% of molybdenum was investigated and detailed data given. The stress-rupture test is considered to be of the most value in the evaluation of steels for use in cracking-still tubes. Molybdenum improves the strength and resistance to temper embrittlement. This improvement increases up to 2% of molybdenum, above which it is not so effective. Vanadium is beneficial in combination with chromium in imparting resistance against hydrogen penetration under high temperature and pressure conditions. Silicon or silicon + aluminium increases the corrosion resistance of these steels, and also their oxidation resistance. Considerable data are given in the form of curves.

**Production and Properties of the Heat-Resisting Fe-Cr-Al Alloys with High Electrical Resistance.** M. Pridantsev and N. Semenova. (Stal, 1939, No. 2, pp. 32–42). Research on the production of Chromel (up to 0·25% of carbon, up to 1·2% of silicon, 28–31% of chromium 2·5–5·0% of aluminium) and Fechral (up to 0·25% of carbon, up to 1·2% of silicon, 13–15% of chromium, 3·5–5·0% of aluminium) is described in detail, and some of the works-production experience is also dealt with. The beneficial effects of low carbon and silicon contents and of additions of about 0·2% of titanium were observed. The casting of ingots was then investigated with reference to bottom pouring, use of chlorinated-resin mould coatings and the filling of moulds with carbon tetrachloride. The cooling of ingots was studied in connection with their tendency to form concentric cracks. Ingots should be heated to 1200–1230° C. for forging or rolling. The removal of surface defects, the heat-treatment, the drawing of wire, the effect of etching on brittleness the effects of temperature, deformation and additions of nitrogen, titanium or zirconium or grain growth, and the permissible service conditions for the iron–chromium–aluminium alloy were also investigated. It was found that only titanium additions had a grain-refining effect. The use of colloidal graphite with a suitable binding material as a lubricant is recommended for the drawing process.

**The Stelliting of Exhaust Valves and Valve Seats.** S. A. J. Sage. (Metallurgia, 1939, vol. 19, Apr., pp. 211–214). The author describes the technique of applying stellite (a cobalt–chromium–tungsten alloy) to the surfaces of valves for aero engines, firstly with the oxy-acetylene torch and secondly by the Wilcox–Rich process.

**New Heat-Resisting Chromium-Aluminium Steels of High Electrical Resistivity.** I. I. Kornilov. (Comptes Rendus (Doklady) de l'Académie des Sciences de l'U.R.S.S., 1939, vol. 24, pp. 904–906 : Chem. Abs., 1940, June, p. 4040). A group of chromium–aluminium–iron alloys of high electrical resistivity, low temperature coefficient of electrical resistivity and good heat resistance has been developed in which the electrical resistivity decreases and the resistance to high temperature increases with decreasing iron content. They may replace Nichrome, Constantan, Manganin, Fechral and Chromel in the construction of rheostats and of heating units for electrical furnaces.

**Investigation of the Equilibrium Diagram of the Ternary System Iron–Chromium–Aluminium.** I. I. Kornilov, V. S. Mikheev, and O. K. Konenko Gracheva. (Comptes Rendus (Doklady) de l'Académie des Sciences de l'U.R.S.S., 1939, vol. 24, pp. 907–910 : Chem. Abs., 1940, p. 4040). The ternary system iron–chromium–aluminium was investigated by the methods of thermal analysis, microstructure and hardness. A region of ternary solid solutions (relatively high chromium and iron content) was found, existing in alloys quenched from 1150° and annealed at the same temperature with subsequent slow cooling. FeCr and $Fe_3Al$ are also found in the solid phase after annealing, for certain iron–chromium–aluminium alloys. The results confirm the theory of Kurnakov that electrical resistivity rises in proportion to the increase in concentration of the substance dissolved in the solid state.

**Technology of a New Heat-Resisting Chromium–Aluminium Steel of High Electrical Resistivity.** I. I. Kornilov and V. S. Mikheev. (Comptes Rendus (Doklady) de l'Académie des Sciences de l'U.R.S.S., 1939, vol. 24, pp. 911–914 : Chem. Abs., 1940, p. 4040). In the manufacture of iron–chromium–aluminium alloys, the aluminium was added to the melt in the form of chromium–aluminium alloy and a synthetic slag, containing lime, magnesium oxide, and alumina, was used to protect the molten alloy surfaces from oxidation. The iron–chromium–aluminium alloys contained much less carbon, silicon, manganese, sulphur, and phosphorus than did Fechral and Chromel ; thus, working properties were improved. Iron–chromium–aluminium alloys containing 10–50% of chromium and 0–10% of aluminium can be forged; those with 0–45% of chromium and approximately 10% of aluminium can be rolled into wires, ribbons, strips, and sheets.

**The Structure and Properties of Heat-Resisting Steels for Tubes.** Ts. N. Rafalovich. (Teoriya i Praktika Metallurgiya, 1939, vol. 11, No. 12, pp. 59–63 : Chem. Abs., 1941, p. 5437).

**Nichrome Furnace of Long Life.** J. G. Winans and S. W. Cram. (Review of Scientific Instruments, 1939, vol. 1, p. 272).

**Investigations of the Shape of Time-Elongation Curves for Various Steels with a New Creep-Testing Apparatus.** H. Esser and S. Eckardt. (Archiv für das Eisenhüttenwesen, 1939, vol. 13, Nov., pp. 209–220). The authors describe an apparatus which they developed for making creep tests ; this apparatus incorporates an automatic temperature controller and an automatic elongation recorder. With this machine the authors obtained time/elongation curves for two carbon steels with different sizes of austenite grains, one molybdenum steel and one chromium–molybdenum–vanadium steel at temperatures of 450° and 500° C.

**Testing Steels for Brittleness at High Temperatures.** E. Siebel and K. Wellinger. (Archiv für das Eisenhüttenwesen, 1940, vol. 13, Mar., pp. 387–392). The authors report on tests made with chromium–nickel–molybdenum steel bolts which showed that embrittlement is associated with a reduction in the notched-bar impact strength and an increase in the hardness, tensile strength, and elastic limit. The tests with this steel included heating it under a load, and it was found that it did not become brittle until a temperature of 470° C. was reached. The embrittlement increased with increasing load, but the authors

also observed that embrittlement occured in a comparatively short time under a load much less than that specified in the German standard method of determining the limiting creep stress.

**Report of Short-Time Creep Tests on Arc Welded Low Carbon Steel.** N. F. Ward. (Welding Journal, 1940, vol. 19, Jan., pp. 14-s–20-s). Description of creep tests which were undertaken to compare the creep at temperatures of 260°, 371°, and 482° C. of unwelded and welded specimens of 0·10% carbon steel (*a*) as cold-drawn; (*b*) cold-drawn and annealed; (*c*) cold-drawn and welded with a coated electrode using alternating current; and (*d*) cold-drawn, welded, and annealed.

**The Mathematical Treatment of Creep Curves.** A. Eichinger. (Archiv für das Eisenhüttenwesen, 1940, vol. 13, Mar., pp. 397–402). In this mathematical discussion the author deals with the characteristics of stress-elongation, time-elongation, and time-stress curves plotted from data obtained in creep tests, and the application of these curves in the estimation of the behaviour of steel at high temperature in industrial practice.

**Reducing Creep in Alloy Steel Bolting Materials.** J. Kanter. (Steel, 1940, vol. 106, Mar. 4, pp. 44–48, 72). In order to simulate the stresses to which pipe-flange bolts are subjected in service, a creep-testing apparatus has been devised with which the rate of creep of steel bars can be determined under diminishing loads.

**Modern Steels to Combat High Temperatures.** C. L. Clark. (Mining and Metallurgy, 1940, vol. 21, Nov., pp. 521–523). The author explains the function of alloying elements, separately and in combinations, in heat-resisting steels. He discussed in particular the low-alloy steels containing chromium, molybdenum, and silicon and their application in high-temperature boiler plant and oil refineries.

**Recent Trends in Corrosion-Resisting and Heat-Resisting Steels.** J. H. G. Monypenny. (Metal Treatment, 1940, vol. 6, Spring Issue, pp. 3–7, 10). The author surveys some recent developments in the manufacture of corrosion and heat-resisting steels, and discusses the development of brittleness as a result of the formation of the sigma phase based on a compound ferrochromium. Investigations of the temperature and speed of formation of this sigma phase have shown that it is formed from ferrite and not from austenite, and that those metals which produce ferrite when added to austenitic chromium–nickel steels may also lead to the formation of the sigma phase if the steels are held for prolonged periods at a dull red heat, thus rendering them brittle.

**Heat and Corrosion Resistant Castings.** D. W. Talbott. (Steel, 1940, vol. 107, July 22, pp. 40–44; July 29, pp. 38–40). The author presents graphs showing the tensile strength and elongation at temperatures in the 538–1093° C. range of the 15/35, 24/12, and 12/60 chromium–nickel steels as well as data on their Brinell hardness, impact strength, specific gravity, Young's modulus, and coefficient of expansion.

**Embrittlement of Creep-Resisting Steels at High Temperatures.** (Metallurgist, 1940, vol. 13, Aug., pp. 121–122). The results obtained by Siebel and Wellinger and by Scherer and Kiessler are considered and the reasons for some of the discrepancies are discussed.

**Creep at High Temperatures.** H. J. Tapsell. (Transactions of the North East Coast Institution of Engineers and Shipbuilders, 1939–1940, vol. 56, pp. 153–164. Engineering, 1940, vol. 149, March 15, 287–288). The author describes the creep characteristics of metals with special reference to the behaviour of carbon and of molybdenum steels. The manner in which the tensile properties such as ultimate stress and limit of proportionality are influenced by creep is first dealt with, and then follows an account of the general behaviour of metals during creep and of the influence of temperatures, stress, and time. The latter half of the paper deals specifically with the creep properties of carbon and molybdenum steels. Considerable variations in the creep properties of carbon steels of similar carbon content have been encountered, and this is illustrated by the data provided, which also show that steels containing from 0·13% to 0·4% of carbon have much the same properties around 450° C. Molybdenum steels of similar composition also vary considerably in creep properties, although they are much superior to carbon steels. The addition of a small percentage of vanadium to molybdenum steels produces further improvement. The effect of heat-treatment is described, particular attention being given to the effect of prolonged heating during service. Methods of estimating working stresses are given, and numerical data and curves show how experimental results may be utilized.

**High-Temperature Rupture and Creep Tests.** E. L. Robinson. (Proceedings of the American Society for Testing Materials, 1940, vol. 40, pp. 811–821) The relation between the results obtained in rupture and creep tests at high temperatures, their graphical representation and their practical application in design are discussed. Data are given for a steel containing carbon 0·14%, molybdenum 0·46%, and for one containing carbon 0·13%, silicon 1·5%, chromium, 4·98%, and molybdenum 0·50%.

**The Automatic Maintenance of Load in Creep Testing.** G. A. Mellor and E. A. Jenkinson. (Journal of Scientific Instruments, 1940, vol. 17, June, pp. 155–156). A description is given of an apparatus designed and in use at the National Physical Laboratory. In this unit there is a 10 : 1 lever arm carrying the load and the end of this arm falls as the specimen creeps. The device provides a means of maintaining the lever arm in its horizontal position as the specimen extends, so that tests can continue for long periods with the minimum of attention.

**Effects of Temperature of Pre-Treatment on Creep Characteristics of 18–8 Stainless Steel at 600 to 800° C.** C. R. Austin and C. H. Samans. (American Institute of Mining and Metallurgy, Technical Publication No. 1181 : Metals Technology, 1940, vol. 7, June). The authors refer to a previous investigation of the creep of a number of alloy steels at 600°, 700°, and 800° C. (*see* Journ. I. and S. I., 1938, No. 1, pp. 177P) in which the preliminary heat-treatment of the specimens consisted of holding for 15 minutes in hydrogen at 950° C. followed by cooling in air. In the present paper they describe a similar investigation of 18/8 steel specimens prepared in three different ways—by holding for 15 minutes at 1150° C., 950° C., and 750° C., respectively, followed by cooling in air. The more important conclusions arrived at are: (1) In confirmation of the work of previous investigators, an increase in the grain-size increases the resistance to deformation of 18/8 stainless steel only at the higher test temperatures; (2) the temperature above which the increase in grain-size becomes effective is 600–700° C.; (3) creep tests at below 600° C. indicate that the temperature of pretreatment has no material effect on the creep characteristics; (4) at 600° and 700° C. the process of carbide-precipitation of 18/8 steel is relatively slow and apparently proceeds for several thousand hours; (5) precipitation seems to occur preferentially in the following places: at the grain boundaries, at the ends and sides of twin bands, and within the grain; (6) two types of precipitate occur, one probably carbide and the other, slightly pink in colour, probably ferritic in nature; and (7) neither the stress nor the plastic deformation accompanying it, in the range studied, seems to have any effect on the character of the carbide precipitate.

**The Creep Strength of 17 Low-Alloy Steels at 538° C.** R. F. Miller, W. G. Benz, and W. E. Unverzagt. (Proceedings of the American Society for Testing Materials, 1940, vol. 40, June, pp. 771–787). The results demonstrated that the creep strength of carbon–molybdenum steel increases with increasing molybdenum content in both the normalized and the normalized and tempered condition. For each composition, the creep strength is higher after normalizing than after normalizing and tempering. The addition of manganese slightly increases the creep strength of normalized and tempered steel containing about 0·5% of molybdenum. Chromium tends to lower the creep strength of molybdenum steels, but increases the stability of their structure. The creep strength of chromium–molybdenum steels is adversely affected by the addition of silicon and aluminium. The addition of titanium or niobium to chromium–molybdenum steel improves its creep strength in the hot-rolled and tempered condition.

**Heat Resisting Steels.** H. E. Arblaster. (Australasian Engineer, 1940, vol. 40, No. 7, pp. 101–104, 108–116). The author first considers the nature of oxide films, the factors affecting their growth and their mechanical properties. He then devotes the major portion of his paper to the properties of the following classes of heat-resisting steel: (*a*) straight chromium steels containing 12–30% of chromium; (*b*) silicon–chromium steels; (*c*) austenitic chromium–nickel steels with and without additions; (*d*) ferrous alloys containing aluminium; (*e*) chromium-manganese steels; and (*f*) alloys high in nickel and chromium, *e.g.*, 60% of nickel and 20% of chromium.

**On Alloy Steels for the Coal-Liquefaction and Other High-Temperature and High-Pressure Chemical Industries.** M. Kinugawa. (Tetsu to Hagane, 1940, vol. 26, Aug. 25, pp. 609–616). The author discusses the suitability of a number of alloy steels for the manufacture of plant to operate at high temperatures and pressures.

**The Creep Properties of a 0·31 per Cent. Carbon, 0·54 per Cent. Molybdenum Cast Steel.** H. J. Tapsell and L. E. Prosser. (Proceedings of the Institution of Mechanical Engineers, 1940, vol. 144, pp. 91–96). Complete creep curves from tests lasting, in some cases, over 10,000 hr. are shown, and the estimated stress-temperature relationships for 0·1% and 0·3% creep in 100,000 hr., and for 0·1% creep in 10,000 hr. are recorded.

**Study of the Effects of Variables on the Creep-Resistance of Steels.** H. C. Cross and J. G. Lowther. (Proceedings of the American Society for Testing Materials, 1940, vol. 40, pp. 125–153). The heat-treatment which produced coarse grains in materials (*a*) and (*b*) improved the creep resistance. The silicon-killed steels had consistently better creep resistance than the rimmed steel, and this applied to both fine- and coarse-grained material. With regard to the steels containing about 0·15% of carbon, in the fine-grained condition, the silicon-killed steel and the silicon–aluminium killed steel to which 1 lb. of aluminium per ton had been added, had creep-resistance properties far superior to those of similar steel killed with 2 lb. of aluminium per ton either with or without silicon. All the steels, which, in their heat-treatment were cooled in air from a temperature producing coarse grains, had better creep-resistance than those cooled in air from temperatures producing fine grains, the greatest improvement being observed in the aluminium-killed steels.

**Note on the Resistance to Furnace Atmospheres of Heat-Resisting Steels.** A. G. Quarrell. (Journal of the Iron and Steel Institute, 1941, No. 2, pp. 49P–61P). The application of the high-temperature method of electron diffraction to thin oxide films formed on a heat-resisting steel has shown that at temperatures up to 950° C. the oxide has a spinel structure. It is suggested that the oxidation resistance of heat-resisting steels is largely due to the formation of a stable spinel. Provided that such elements as nickel, chromium, and aluminium are present in sufficient quantities, the spinel structure should be stabilized, and the absence of lattice changes on heating and cooling will prevent easy access of oxygen to the underlying metal surface and so greatly increase the oxidation resistance.

**The One-Hour Stepped Test as a Rapid Method of Determining Creep Strength.** H. Esser and S. Eckardt. (Archiv für das Eisenhüttenwesen, 1940, vol. 13, June, pp. 533–537). In a previous investigation of creep-testing methods by the present authors (*see* Archiv für das Eisenhüttenwesen, 1939, vol. 13, pp. 209–220). it was established that a quantitative evaluation of the creep strength of steel specimens could be made from observations of the permanent elongation at the end of one hour's application of each successive load. This is referred to as the one-hour stepped test. In the present paper the authors study the effects of the pre-heating time, the time during which the load is removed, the number of steps, and the value and duration of the preliminary load on the results obtained by this test, and find them to be very small. As the scatter of the plotted results is small and the time required is short, this test is thought to be a useful and reliable means of maintaining a constant check on the creep properties of steel.

**The Creep Strength of Heat-Resisting Steels at 600°, 700° and 800° C.** A. Pomp and A. Krisch. (Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung, 1940, vol. 22, No. 9, pp. 137–148). The authors describe a series of creep tests of several hundred hours' duration at temperatures in the range 600–800° C. on twenty different steels comprising three chromium–molybdenum steels, six chromium–manganese steels, six chromium–nickel steels and five chromium–cobalt steels. The tests were made by the German standard method DVM-A117; this method determines the maximum stress at which an initial elongation of the material will in course of time cease to increase but which, if exceeded, will cause a continuous elongation until fracture occurs. However, at the above temperatures this method of testing did not give satisfactory values.

**The Effect of Alloying Additions on Some of the Properties of Heat-Resisting Iron–Aluminium Alloys.** H. Cornelius and W. Bungardt. (Archiv für das Eisenhüttenwesen, 1940, vol. 13, June, pp. 539–542). The authors report on their investigation of the structure, forgeability, bending-impact strength, hardness, and scale formation of iron–aluminium alloys with 5–10% of aluminium at 1100° C. in air. In particular the effect of separate additions of carbon, manganese, nickel, cobalt, copper, silver, silicon, chromium, tungsten molybdenum, vanadium, titanium, boron, and niobium + tantalum, were examined. The brittleness of the alloy can be considerably reduced by small additions of titanium and niobium + tantalum without detriment to the other properties, but even in this improved state the alloy is still too brittle to be used as a scale-free forgeable material. The addition of boron also reduces the brittleness, but this element is very detrimental to the scaling resistance.

**Equations for the Time-Elongation Curves in Creep-Tests.** F. Bleilöb. (Archiv für as Eisenhüttenwesen, 1940, vol. 13, May, pp. 489–496). In this mathematical discussion the author develops formulæ for the interpretation of the results of creep tests; in particular he works out a basic formula which expresses the influence of both time and load at constant temperature.

**Preliminary Test Results for Chromium–Molybdenum–Vanadium Steel "EI-10" for the Connection of Flanges Operating at Temperatures of 450–500° C.**. W. Larichev. (Iron and Steel Institute, 1942, Translation Series, No. 86).

**Chromium–Manganese Steel for Valves.** M. P. Braun. (Novosti Tekhniki, 1940, No. 5, p. 16: Chem. Abs., 1940, p. 5808). As possible substitutes for chromium–nickel valve steel the following compositions were tested: (1) manganese 11%, chromium 14%, and tungsten 2%, and (2) manganese 6%, chromium 16%, and molybdenum 3%. At 900° C. the first steel after hardening in oil from 1100° C. had a tensile strength of 17 kg./sq. mm., impact toughness of 25 kg./sq. cm., and Brinell hardness of 200–220.

**Relation of Grain Size to Creep Strength of Carbon-Molybdenum Steel.** S. H. Weaver. (General Electric Review, 1940, vol. 43, pp. 357–364). Tests were made to determine whether a steel at creep temperatures above the lowest temperatures of crystallization had a maximum creep strength obtained by a corresponding optimum size of the structural grain when there was no appreciable difference in the microstructure in each grain; or whether the creep strength merely increases with the grain-size until influenced by a changed structure within the grain.

**Technical Creep Strength, Fatigue Strength and Their Relation to the True Creep Limit.** U. Dehlinger. (Zeitschrift für Metallkunde, 1940, vol. 32, pp. 199–200). The true creep strength is defined as a stress limit under which the initial elongation eventually stops. The technical (measured) creep strength is merely an approximation of this theoretical value determined during a limited period. By theoretical consideration and actual experiments it is shown that the true creep limit, is, in the lower range, independent of temperature and coincides with the fatigue limit; the technical creep strength is considerably higher. At higher temperatures as soon as recrystallization appears this is no longer true; in that case technical creep strength is lower than the fatigue strength.

**A Two-Load Method of Determining the Average True Stress-Strain Curve in Tension.** C. W. McGregor. (Journal of Applied Mechanics, 1939, vol. 6, Dec., pp. A-156–A-158). The complete average true stress-strain curve in tension may be determined for a material from the begining of yielding to fracture, under ordinary testing speeds, by the observation during the test of two values of the changing load applied to a tapered specimen, namely, the maximum load and the load at fracture. In this method the diameters at various positions along tapered specimens are measured before and after the test, and stress and reduction of area values are computed from these observations.

**The Development of Alloys for Use at Temperatures above 538° C.** E. R. Parker. (Transactions of the American Society for Metals, 1940, vol. 28, p. 797). The author discusses some of the factors which affect the resistance of metals and alloys to deformation at high temperatures. He points out that whilst the thermal activity of atoms is a factor which need not be considered with regard to deformation at low temperatures, it is of great importance at high temperatures. In examining the properties of specimens under stress at temperatures above 538° C., the author has found that alloys containing precipitates of the new type $Fe_2W$, $Fe_2Mo_2$, $Fe_3Nb_2$, $Fe_2Ta$ and $Fe_2Ti$, possess greater resistance to deformation than alloys which depend on carbides for their strength. He reports on a series of tensile tests at room temperature and at 538° C. on specially prepared alloys containing the metals indicated above and on the relation of recrystallization temperature to the results obtained. The results of this work support the hypothesis that a dispersed phase of an intermetallic compound which does not agglomerate rapidly at 593°–649° C. has a great stabilizing influence and that alloys containing such compounds have a high creep resistance.

**Fundamentals of High Temperature Testing of Steel.** J. Glen. (Journal of the West Scot. Iron and Steel Institute, 1940–41, vol. 48, Pt. II, pp. 19–34). The author describes and explains the mechanicsm of the strain-hardening and strain-ageing of steel, with particular reference to the effects of time and temperature. Some American, German and English methods of determining the creep properties of steel and of presenting and interpreting the results are described.

**How Grain Size Affects Creep Strength.** S. H. Weaver. (Steel, 1941, vol. 108, Feb. 24, pp. 80–85, 92). Steels from four heats of 0·20% carbon steel alloyed with small quantities of chromium, nickel, tungsten and molybdenum in various combinations and heat-treated to produce different grain-sizes were used in the creep tests. It was apparent from long-time creep tests at 550° and 600° C. that all four types of steel had better creep properties in the annealed than in the normalized and in the tempered states, and that each of the four types had a different optimum grain-size for the highest creep strength. An analysis of the results of many creep tests showed that: (*a*) At the lowest temperature of testing the steel with the finest grain had the greatest creep strength; (*b*) at the highest temperature the steel with the coarsest grain had the greatest creep strength; and (*c*) at intermediate temperatures the greatest creep strength was exhibited by the steel with an intermediate grain-size.

**Young's Modulus and Recovery in Creep Tests.** H. Esser and S. Eckardt. (Archiv für das Eisenhüttenwesen, 1941, vol. 14, Feb., pp. 397–401). An investigation of the recovery of steel specimens after creep tests and how this is affected by the load, the duration of the load and the temperature are described.

**Creep Tests with Stepped Increasing Loads at 700° and 800° C.** A. Krisch and S. Eckardt. (Archiv für das Eisenhüttenwesen, 1941, vol. 14, Mar., pp. 451–453). The authors describe an investigation, by means of 1-hr. and 10-hr. stepped tests at 700° and 800° C. of the creep properties of four of the austenitic chromium–manganese steels and two of the chromium–cobalt steels which were subjected to long-term tests by Pomp and Krisch. The 1-hr. stepped test was described recently by Esser and Eckardt. A comparison of the results obtained by the short-time and the long-time tests showed that the values obtained by the former were too high, so that long-time test are necessary for the correct evaluation of the creep properties of these steels at high temperatures.

**The Influence of Temperature on Creep Strength.** H. Esser and H. Schmitz. (Archiv für das Eisenhüttenwesen, 1941, vol. 15, July, pp. 19–25). This investigation is a continuation of the creep-strength investigations reported previously by Esser and Eckardt. The results of short-time creeps tests on two low-carbon steels and two chromium–molybdenum steels at temperatures in the 300–600° C. range are reported. The test in 10-hr. stages can be used to determine the creep strength at normal testing temperatures by extrapolation without serious errors arising.

**Heat-Resisting Steels.** (Automobile Engineer, 1941, vol. 31, Nov. 6, pp. 371–373). The characteristics of heat-resisting alloy steels containing silicon, nickel and chromium are discussed with particular reference to the effect of scaling and creep on their mechanical properties at temperatures exceeding 300° C. Reference is made to the "time-yield" short-time creep test at elevated temperatures developed by the Brown–Firth Research Laboratories.

**The Determination of the Creep Strength of Steel at Temperatures above 600° C.** A. Krisch. (Archiv für das Eisenhüttenweseen, 1941, vol. 14, Jan., pp. 325–332). An abridged account of a previously published investigation by Pomp and Krisch on the creep strength of heat-resisting steels at 600°, 700° and 800° is presented.

**The Effect of Carbide Spheroidization upon the Creep Strength of Carbon–Molybdenum Steel.** S. H. Weaver. (Proceedings of the American Society for Testing Materials. 1941, vol. 41, pp. 608–627). Two independent series of long-time creep tests were run on specimens in various conditions of heat-treatment, one series at 482° C., the other at 537° C. Data showed that whilst the initial creep stresses varied greatly for the different conditions of the steel, in some cases the creep stresses after 20 years at 482° C. and 537° C. would decrease by 54% and 77% respectively. The tests at 482° C. indicated that the normalized structure was of primary importance in producing good creep properties, whilst tests at 537° C. showed that the coarse grain was of major importance and the effect of either normalizing or annealing was only of minor importance.

**The Properties and Mode of Rupture of a Molybdenum and a Molybdenum Vanadium Steel, Judged from Prolonged Creep Tests to Fracture.** H. J. Tapsell, C. A. Bristow and C. H. M. Jenkins. (Proceedings of the Institution of Mechanical Engineers, 1941, vol. 146, No. 5, pp. 208–219). The authors describe an investigation of the creep properties of a 0·49% molybdenum steel and a 0·54% molybdenum, 0·20% vanadium steel, which was made primarily to provide data on the mode of failure and elongation at fracture. Observations made at intervals of about five days on the former steel showed that the commencement of spheroidization and intercrystalline cracking became evident simultaneously after 33 days of test when the extension was 1·35%, a stress of 7 tons per sq. in. being applied at 580° C.

**The Present Position of Rolled and Forged Heat-Resisting Steels.** G. Riedrich. (Stahl und Eisen, 1941, vol. 61, Sept. 11, pp. 852–858). The author reviews the chemical composition, structure, scaling resistance and mechanical and physical properties of the heat-resisting steels now in use. The heat-resistance of austenitic chromium–nickel steels is increased by silicon additions, but if over 3% is added the resistance to hot-deformation is increased. The chromium–manganese–silicon steels may, however, contain more than 3% of silicon without the hot-working properties being affected. In the ferritic chromium steels 2·5–3% of silicon can replace about 10% of chromium and give equal heat resistance. Ferritic and ferritic-austenitic steels high in chromium are resistant to sulphuretted hydrogen and in carburizing atmospheres. The tendency to brittleness due to the precipitation of FeCr of ferritic-austenitic steels with about 25% of chromium and low in nickel can be counteracted by keeping the nickel below 3%. Ferritic steels become cold-brittle after prolonged loading at temperatures exceeding 950° C., whilst the ferritic-austenitic steels do not. Ferritic steels with more than about 15% of chromium also become cold-brittle after prolonged stressing in the 400–500° C. range and this is more marked with increasing chromium content.

**The Application Possibilities of Stainless and Heat-Resisting Steels Containing Nitrogen Additions.** F. Rapatz. (Stahl und Eisen, 1941, vol. 61, Nov. 27, pp. 1073–1078). The author reviews the chemical composition, production, working-up, properties and possible applications of steels containing chromium, chromium and nickel manganese, and chromium and manganese, to each of which more than 0·05% of nitrogen was purposely added in the bath. The nitrogen extended the stability range of the austenite and improved the properties of the austenitic steels. The high creep strength of the steels containing nitrogen, especially the chromium–manganese–nitrogen steels, renders them suitable for use at high temperatures, but they are only non-scaling at up to 850° C.

**Investigation on the Suitability of Heat-Resistant Materials for Combustion Engines. Part III.** H. Cornelius and W. Bungardt. (Luftfahrt-Forschung, 1941, vol. 18, Aug. 20, pp. 275–279 : Iron and Steel Institute, 1941, Translation Series, No. 63). An account of an investigation of the creep strength in tension at temperatures between 600° and 1000° C. of twenty-two austenitic steels of industrial and special experimental quality. Data on the thermal expansion, specific gravity, modulus of elasticity, change of strength properties after annealing, and resistance to scaling are given.

**The Scaling-Resistance of Steels Alloyed with Vanadium.** H. Cornelius and W. Bungardt. (Archiv für das Eisenhüttenwesen, 1941, vol. 15, Aug., pp. 107–113 : Iron and Steel Institute, Trans. No. 109). The authors report the results of tests on the influence of additions of up to 4·70% of vanadium to plain and alloy steels on the scale formation at different temperatures. At temperatures up to 900° C. the addition of vanadium slightly increased the scaling resistance of unalloyed steels ; at higher temperatures the vanadium had no effect. Between 0·5% and 2·0% of vanadium had practically no effect on the scaling resistance of steels containing chromium, chromium and silicon, chromium and manganese, and chromium and nickel (not too high in nickel) at temperatures at which these steels normally have a good resistance to scaling. At higher temperatures 2% of vanadium increased the scaling resistance of all these steels. The scaling of chromium–nickel steels high in nickel was only slightly changed by adding 0·5% of vanadium, whilst 2% of vanadium markedly decreased their scaling resistance. The time taken for the normal initial scaling of a chromium–nickel steel decreased with increasing nickel content, and after this there was a rapid increase in the scale formation ; this also occurs with iron–aluminium alloys, The amount by which vanadium additions increased the scaling of the steels high in nickel on annealing in the products of combustion of town gas was much less than when the specimens were heated in air. A metallographic investigation was made of the effects of the scaling on the steel/scale interface.

**Relaxation of Metals at High Temperatures.** W. E. Trumpler, jun. (Journal of Applied Physics, 1941, vol. 12, No. 3, pp. 248–253). Automatic apparatus for the measurement of relaxation of metals at high temperature is described. In this the specimen is elongated a given amount, and then maintained at this increased length by means of a changing applied stress, *i.e.* an initially pure elastic strain is gradually transformed into a permanent strain. Results of tests on heat-resisting steels are given. The rapidity and exceptional accuracy of the test suggest that it offers a new standard method for the comparison of materials.

**Some Creep Properties of 16Cr–13Ni–3 per cent. Mo Steel.** H. D. Newell. (Metals and Alloys, 1941, vol. 14, Aug., pp. 173–180). The author discusses the results of creep tests on steels containing chromium 16%, nickel 13%, and molybdenum 3%. Some tests at temperatures in the 315–871° C. range on steel of this type containing only 0·074% of carbon revealed that at 593° C. the material yielded in a rapidly recurring series of slips, not noted at 648° C. and above, less notable and of lower frequency at 537° C. and 482° C., and only slightly discernible at 426° and 315° C.

**Special Phenomena in Connection with the Scaling of Heat-Resistant Steels and Alloys.** G. Bandel. (Archiv für das Eisenhüttenwesen, 1941, vol. 15, Dec., pp. 271–283 : Iron and Steel Institute, 1942, Translation Series, No. 116). The author points out that two fundamentally different types of scale may be formed on heat-resistant steels, *viz.*, (*a*) scale consisting of the oxide of the effective alloy component, *i.e.*, that which is most liable to oxide formation, and (*b*) scale consisting of iron oxides. Occasionally both types of scale are found on the same specimen. A layer of the former type forms an effective protection against further scaling, whereas the latter has little protective value at temperatures above 550° C., owing to the great permeability of iron oxides to oxygen at high temperatures. The author discusses the conditions which lead to the formation of the two types of scale.

**The Problem of the Safety of Boiler Tubes with Regard to Internal Pressure at High Temperatures.** C. A. Duckwitz and H. Buchholtz. (Archiv für das Eisenhüttenwesen, 1941, vol. 15, Nov., pp. 235–242). The authors report the results of internal-pressure tests and creep tests in accordance with the German standard creep-testing procedure A117–118 on boiler tubes of unalloyed 0·12% carbon steel.

**Creep-Strength and Internal-Pressure Tests on Welded Tubes of Mild Unalloyed Steel.** C. A. Duckwitz. (Archiv für das Eisenhüttenwesen, 1941, vol. 15, Dec., pp. 285–289). The author subjected welded tubes of mild unalloyed steel (St 35.29 with 0·12% of carbon) to tensile tests (between 20° and 600° C.), creep tests (German standard method A117/118 at 400° to 600° C.), and internal-pressure tests. He tested tubes welded with circumferential as well as with longitudinal beads. The creep tests confirmed an observation made previously on other qualities of steel, *viz.*, that the creep strength of the weld is, as a rule superior to that of the unwelded material.

**Brittleness and Damage to Heat-Resisting Steels when Subjected to Creep Stresses.** A. Thum and K. Richard. (Archiv für das Eisenhüttenwesen, 1941, vol. 15, July, pp. 33–42). The authors discuss the cause of the brittle fracture of low-alloy heat-resisting steel bolts under high-temperature-service conditions. Experiments with plain and notched bars of various heat-resisting steels under prolonged static loading mostly at 500° C., show that up to 16,000 hr. no indication of a limiting creep stress is to be found. Chromium–nickel–molybdenum steels, showing a tendency to embrittlement, have their creep resistance markedly lowered by notches, the effect being considerably greater than would be assumed from short-time creep tests. On the other hand steels not subject to embrittlement may even have their creep resistance increased by notches. The total deformation at fracture may either increase or decrease with increasing time of loading, according to the embrittling properties of the steel.

**The Embrittlement of High-Chromium Steels in the 300–600° C. Temperature Range.** G. Riedrich and F. Loib. (Archiv für das Eisenhüttenwesen, 1941, vol. 15, Oct., pp. 175–182). An investigation of the embrittlement of specimens of 48 chromium steels containing from 5% to 29% of chromium after quenching from various temperatures in the 300–600° C. range. With up to about 15·5% of chromium there was no embrittlement. Steels with 15·5–18% of chromium were fairly brittle and with 19% and more they were very brittle. The quenching temperature range which caused brittleness was 400–500° C., the greatest brittleness occurring after quenching from 475° C. Both titanium and columbium, when added separately, increased the brittleness. After quenching from 475° C. the amount of chromium necessary to cause brittleness was somewhat higher with 3% of manganese in the steel than when the normal percentage of manganese was present. Up to 2·8% of silicon did not affect the minimum amount of chromium required to produce brittleness, but it shortened the holding time necessary to cause brittleness. Changes in the carbon content in the 0·04–0·28% range had only a very slight effect on the embrittlement tendency.

**The Strength of Steels at High Temperatures.** M. Ros and A. Eichinger. (Eidgenössische Materialprüfungs und Versuchsanstalt für Industrie, Bauwesen und Gewerbe, Zürich, 1941, Nov., Report No. 138 : Journal of the Iron and Steel Institute, 1944, No. 2, p. 26A). The results of short-time and long-time creep tests at 400°, 450°, 500°, 550°, 600° and 700° C. on steels alloyed with (*a*) chromium and molybdenum, (*b*) chromium, nickel and tungsten, (*c*) chromium, nickel and titanium, (*d*) chromium, nickel, tungsten and vanadium, and (*e*) chromium, nickel, tungsten, vanadium and titanium, are reported. The effect of previous cold work on the creep properties was also investigated.

**Effect of Structure on the Creep Resistance of an Austenitic Steel.** M. Sedille and E. Morlet. (Comptes Rendus, 1941, vol. 213, pp. 615–617). The steel contained carbon 0·24%, silicon 1·43%, manganese 0·76%, nickel 8·63%, chromium 19·43%, and tungsten 3·92%. All samples were heated at 1150° for one hr. and tempered at 800° for 6 hr. Five samples were rolled or forged to various thicknesses and showed 290 to 8 grains per sq. mm. In another sample the grains were increased in size to 1–2 grains per sq. mm. by heating for 2 hr. at 1200–1225°. The creep between the 25th and 35th hr. at loads of 5, 7, and 9 kg./sq. mm. at 750° was measured. The creep decreased with increase in grain-size.

**Steels Resistant to Scaling at High Temperatures.** F. M. Capuano. (Metallurgia Italiana, 1941, pp. 189–198 : Chem. Abs., 1945, Oct. 10, p. 4309). A review of the theory of oxidation of steel at high temperatures, of the behaviour of various scaling-resistant steels and of the effect of the alloying constituents on the resistance to scaling leads to the conclusions that the resistance to scaling is mainly due to chromium and is proportional to the chromium content. Aluminium and silicon (1–2%) increase the resistance to scaling of chromium-rich steels ; tungsten and cobalt have no appreciable effect, chromium–manganese and chromium–silicon steels resist scaling only up to 800° and to 950° C., respectively.

**Fabrication of Carbon–Molybdenum Piping for High-Temperature Service.** R. W. Emerson. (Proceedings of the American Society for Testing Materials, 1941, vol. 41, pp. 579–604, discussion, pp. 605–607). A study was made on the effect of hot-work, such as upsetting, hot-bending, forging and welding on the physical properties and microstructure of low-carbon, 0·5% molybdenum steel pipe for use at temperatures from 399–566° C.

**Determination of Creep Limits in Steels—Comparison of Long- and Short-Term Tests.** G. Wallgren. (Ingeniörs Vetenskaps Akademien Handlingar, 1941, vol. 31, No. 160 : Chem. Abs., 1942, May 20, p. 2826). Results from creep measurements at slow rates (elongation of 0·00001%/hr. for 500–1000 hr.) were compared with previous measurements of rapid rate. Agreement is good up to 450° C., but above this temperature the slow rates give lower values, probably because of structural changes.

**Correlation of High-Temperature Creep and Rupture Test Results.** R. H. Thielemann. (Transactions of the American Society for Metals, 1941, vol. 29, pp. 355–368). Data are given for steel containing nickel 1·84%, chromium 0·72%, molybdenum 0·34%, carbon 0·42% ; chromium 0·99%, molybdenum 0·35%, vanadium 0·26%, carbon 0·45% ; molybdenum 0·49%, carbon

0·17%; and chromium 7·42%, silicon 0·95%, molybdenum 0·99%, carbon 0·11% at temperatures from 482° to 704° C. to show that both creep and rupture properties must be known to evaluate behaviour over long periods of time.

**Properties of Steels as a Basis for Design for High-Temperature Service.** H. J. Tapsell and A. E. Johnson. (Proceedings of the Institution of Mechanical Engineers, 1941, vol. 144, pp. 97–106). Creep occurs in three stages : an early period over which it is diminishing, a period of steadiness, and a final stage of increasing creep to the point of failure ; the third stage is reached with a diminishing total deformation as the temperature rises. Steels of similar composition may vary considerably in creep-resistance. The onset of spheroidization or grain-coarsening during service (encouraged by severe cold-work) weakens the steel. Data useful as a basis for design are presented.

**The Corrosion of Steel and Various Alloys by High Temperature Steam.** H. L. Solberg and others. (Journal of the American Society of Naval Engineers, 1941, vol. 53, Nov., pp. 705–723). Report of investigations at Purdue University, designed to determine the effect of steam pressure, surface shape and finish of steel, duration of exposure temperature (538–705° C.) and temperature fluctuations, on corrosion resistance and scaling.

**Investigation of the Behaviour of Metals under Deformation at High Temperatures—Part II. Structural Changes in Carbon Steels Caused by Creep and Graphitisation.** C. H. M. Jenkins, G. A. Mellor, and E. A. Jenkinson. (Journal of the Iron and Steel Institute, 1942, No. I, pp. 51P–86P). A study was made of the behaviour of carbon steels by means of the microscopical examination of test-specimens from short-time (tensile) and long-time creep tests. The specimens were tested in a high vacuum over the temperature range 15–950° C. In the majority of cases the stress applied was sufficient to cause rupture. The materials examined had various carbon contents up to 1·14%. The effect of the carbon content was most noticeable in short-time (tensile) tests, but as the temperature of test was increased this effect was reduced.

**The Behaviour of Steels at Elevated Temperatures.** A. Pomp. (Stahl und Eisen, 1942, vol. 62, pp. 571–575). A review of outstanding investigations during 1941 for some steels, stainless steels and zinc alloys.

**Precision in Creep Testing.** J. A. Fellows, E. Cook, and H. S. Avery. (Metals Technology, 1942, vol. 9, Aug., Technical Publication No. 1443). An account of apparatus and technique developed for the creep testing of chromium–nickel heat-resisting steels. The laboratory is designed to permit 1000-hr. tests at temperatures in the 649–1204° C. range with a choice of applied stress extending from 50 to 50,000 lb. per sq. in. in increments of 50 lb. per sq. in. Specimens 16 in. long with a 4-in. gauge length are used, and the elongation measurements are made by sighting a telescope with crossed hair lines on reference marks cut in platinum–rhodium extensometers spot-welded to each side of the gauge length. Exceedingly accurate measurements can be made, because one drum division of the micrometer eyepiece is equivalent to 0·00000978 in. per inch for a 4-in. gauge length.

**Engineering Properties of Heat-Resistant Alloys.** H. S. Avery, E. Cook, and J. A. Fellows. (American Institute of Mining and Metallurgy, Technical Publication No. 1480 : Metals Technology, 1942, vol. 9, Aug.). An investigation of the properties of 26/12 chromium–nickel type of steel at temperatures between 760° and 1093° C. Between 0·20% and 0·40% of carbon the creep strength is approximately doubled by an increment of 0·10% of carbon with a simultaneous reduction in the ductility. At 982° C. the limiting creep strength varies directly with the carbon content up to nearly 0·50% carbon. Ferrite-forming elements such as chromium, silicon, tungsten or molybdenum can be employed to increase the ductility at the expense of tensile strength. Nickel, nitrogen and carbon increase the strength at the expense of ductility. Differences in the strengths of alloys with varying amounts of ferrite suggested that magnetic-permeability measurements could be used to predict the probable creep strength of this type of alloy.

**Review of Recent Research into the Influence of Vanadium and Molybdenum upon the Creep Strength.** D. W. Rudorff. (Metallurgia, 1942, vol. 26, June, pp. 43–46). Recent work on the influence of vanadium and molybdenum on the creep strength of heat-treated steels is reviewed by the author, his information being based on the paper by Holtmann. (See following abstract).

**The Influence of Alloying Elements on the Tensile Strength and Creep Strength of Heat-Treated Steels.** W. Holtmann. (Stahl und Eisen, 1942, vol. 62, Jan. 8, pp. 32–35). The author reports on an investigation of the effect of the carbon content on the tensile and creep properties at 20°, 500°, and 550° C. of steels alloyed with vanadium and molybdenum, and reviews the work of other investigators on similar steels. The results are shown in an unusual way by curves drawn through points of approximately equal creep strength, which are plotted on graphs with the carbon contents as ordinates and the molybdenum or vanadium contents as abscissae.

**The Testing of the Scaling Resistance of Alloy Steels.** G. Bandel and K. E. Volk. (Archiv für das Eisenhüttenwesen, 1942, vol. 15, Feb., pp. 369–378). The authors discuss the possibilities for the standardization of tests on the scaling resistance of heat-resistant steels. They discuss numerous testing methods described in the literature with regard to their suitability for routine work, and arrive at the conclusion that a method based on the determination of the loss in weight would be best as a standard scaling test.

**The Embrittlement of High-Alloy Chromium Steels in the Temperature Range of about 500° C.** G. Bandel and W. Tofaute. (Archiv für das Eisenhüttenwesen, 1942, vol. 15, Jan., pp. 307–320). The authors studied the cause of the embrittlement frequently observed in ferritic, or mainly ferritic, high-chromium steels after long periods of annealing at about 500° C. For this purpose they produced in a high-frequency furnace experimental casts of steels or alloys with 9–70% of chromium with the following additions : carbon, nickel, manganese, molybdenum, silicon, aluminium, titanium, and phosphorus. The specimens prepared from these casts were annealed for up to 5000 hr. at temperatures between 350° and 1100° C., in most cases between 400° and 550° C. The effects of the annealing time and temperature, of the alloy additions and of various modes of heat-treatment before annealing at about 500° C. were studied.

**The Present Stage of Development of Heat-Resistant Cast Steel.** F. Schulte. (Stahl und Eisen, 1942, vol. 62, May 7, pp. 389–397). A detailed review of the more common compositions, the mechanical and scaling-resisting properties, the casting properties and the uses of chromium–molybdenum cast steels of high hot-strength and of heat-resistant chromium cast steels. Special consideration is given to the possibility of replacing molybdenum in hot-strength castings, and chromium and nickel in heat-resistant castings.

**The Effect of Columbium on the Creep Strength of Steel.** W. Peter. (Archiv für das Eisenhüttenwesen, 1942, vol. 15, Feb., pp. 364–368). The author discusses the effects of the carbon content, the quenching and tempering temperatures and the structure on the

mechanical properties, especially the creep strength, of columbium-bearing steels. He points out that the quenching temperature required for the achievement of maximum creep strength can be lowered by adding about 1% of silicon. By comparing the creep strengths of alloys with 1% and 2% of columbium and a variety of carbon contents, the author proved that the favourable effect of columbium is due solely to the formation of iron columbide, not to that of columbium carbide. It was thus possible to obtain good creep strength values with columbium contents of only 0·2%, provided that the carbon content was lowered at the same time.

**Precipitation Hardening and Creep Strength of Iron-Columbium Alloys and of Steels Alloyed with Columbium.** F. Wever and W. Peter. (Archiv für das Eisenhüttenwesen, 1942, vol. 15, Feb., pp. 357–363). The authors point out that in iron–columbium alloys containing more than 0·5% columbium a columbide is formed the solubility of which increases considerably with the temperature, so that it is possible to harden iron–columbium alloys by quenching with subsequent tempering at 500–700° C. The creep strength and the yield point increase with the hardness, whereas the notched-bar impact strength decreases.

**Niobium as an Alloying-Element in Heat-Resisting Steels.** D. W. Rudorff. (Metallurgia, 1942, vol. 26, Oct., pp. 193–196, 224). An abridged English version of the above.

**The Physical Properties of Materials for Steam Power Plants.** F. J. Cowlin. (English Electric Journal, 1942, vol. 10, June, pp. 121–127). The author describes some of the creep-testing equipment at the National Physical Laboratory and at the Westinghouse Electric and Manufacturing Co. at Pittsburgh. The photo-elastic method of studying stress distribution in models of celluloid or resin compounds is explained.

**Mechanics of Creep for Structural Analysis.** J. Marin. (Proceedings of the American Society of Civil Engineers, 1942, vol. 68, May, pp. 719–735). In this mathematical treatise the author develops a theory for determining the influence of creep at normal temperature as a factor in structural design.

**Welding Chromium Steels. Part II—Welding Aircraft Chromium-Molybdenum Steels. Part III—Welding Heat-, Wear- and Corrosion-Resistant Chromium Steels.** W. Spraragen and H. H. Chiswick. (Welding Journal, 1942, vol. 21, Sept., pp. 389-s–415-s). The authors present a comprehensive review of the literature from July, 1937, to December, 1941, on the welding of chromium–molybdenum aircraft steels, chromium–silicon–molybdenum heat-resisting steels, 4–6% chromium steels and chromium–nickel stainless steels.

**The Reduction in the Stress in Steel Bolts under Load at High Temperatures.** K. Wellinger and E. Keil. (Archiv für das Eisenhüttenwesen, 1942, vol. 15, Apr., pp. 475–478 : Iron and Steel Institute, 1943, Translation Series, No. 154). The authors describe an apparatus, with which they obtained time-stress curves for bolts and nuts of low chromium–nickel–molybdenum steel and of plain carbon steel at 500° C.

**Rust-, Acid- and Heat-Resisting Steels.** W. H. Hatfield. (Institute of Chemistry, May, 1942). The author begins by indicating how the war emergency has affected the special-steel situation and presents a list of purposes for which rust-, acid- and heat-resisting steels are considered essential and not essential in war-time. The properties and microstructures of these steels are then briefly discussed. The heat-resisting steels are divided into following groups: (1) silicon–chromium steels; (2) 12–30% chromium steels; (3) austenitic chromium–nickel steels; and (4) high nickel–chromium alloys containing 60% or more of nickel. The "time-yield" method of assessing creep characteristics is explained. One of the latest heat-resisting steels can be stressed at up to 6·5 tons/sq. in. at 700° C. without the above creep rate being exceeded.

**The Tensile-Impact Resistance of Carbon–Molybdenum Welds at Elevated Temperatures.** O. H. Henry and M. A. Cordovi. (Welding Journal, 1942, vol. 21, Sept., pp. 416-s–420-s). The authors report the results of hardness, tensile and impact tests at temperatures of + 21°, 288°, 410°, 482° and 538° C. on specimens cut from welded joints in tubing in which a tube of 2·25% chromium 1%-molybdenum steel was welded to a 1% molybdenum steel tube using molybdenum-steel electrodes.

**True Stress-Strain Relations at High Temperatures by the Two-Load Method.** C. W. MacGregor and L. E. Welch. (American Institute of Mining and Metallurgy, Technical Publication No. 1507 : Metals Technology, 1942, vol. 9, Sept.). A method of obtaining true stress-strain data in tensile tests by observation of the maximum load and the load at fracture has already been described by C. W. MacGregor (see J. Applied Mechanics, 1939, vol. 6, Dec., pp. A156–A158). The authors now report on an investigation of the application of this method to short-time tensile tests at high temperature. The results of tests on two carbon steels, one low-alloy steel, three high-alloy steels, brass and Monel are presented. The conclusions reached were: (1) The two-load method can be used in the short-time high-temperature test provided appreciable creep does not occur during the test: (2) The true stress-strain curves are linear from the point of maximum load to that of incipient fracture; (3) the effect of heat on the true stress at the maximum load and on the average true stress at fracture was different for most of the materials tested; (4) the ductility of metals at high temperatures can be pictured by comparing the true uniform strain with the true local necking strain; (5) the effect of heat upon the two strains referred to in (4) was different; and (6) heat affected the true strain at fracture and the true local necking strain in a similar manner.

**The Creep Strength of Steel at Room Temperature.** A. Krisch. (Archiv für das Eisenhüttenwesen, 1942, vol. 15, June, pp. 539–542 : Iron and Steel Institute. Trans. Series, No. 161). The author reports the results of creep tests at room temperature on specimens of two ordinary carbon steels, one low-chromium–molybdenum steel, a steel containing chromium 14·8% and nickel 0·22%, and an 18/8 stainless steel containing 0·20% of molybdenum.

**The Hot Elongation Properties of Steels Loaded in Tension.** J. de Lacombe. (Revue de Métallurgie, Memoires, 1942, vol. 39, Apr., pp. 105–111; May, pp. 152–158; June, pp. 181–188). Apparatus is described with which time-elongation curves were obtained on steel specimens loaded in tension at temperatures in the 380–800° C. range. Low-carbon steels with and without molybdenum, chromium–molybdenum steels, nickel–chromium–molybdenum steels and austenitic nickel–chromium steels were tested. Changes in length of the order of $10^{-3}$ mm. were recorded photographically without difficulty. Most of the tests were run for periods of 25–35 hr. The curves obtained were subjected to a mathematical analysis by a method explained in a previous paper (Revue de Métallurgie, Memoires, 1939, vol. 36, Apr., pp. 178–188). The main part of the present paper contains a mathematical analysis of the test results in which the possibility of extrapolating them for periods up to 10,000 hr. is closely examined. It is concluded that in most cases tests lasting 1000 to 2000 hr. would be necessary to obtain data for extrapolation to 10,000 hr.

The effects of temporary removal of the load were also studied.

**The Status of the Heat-Resisting Constructional Steels.** K. Kreitz. (Archiv für das Eisenhüttenwesen, 1942, vol. 15, May, pp. 491–496). Methods of determining the creep strength of steel and the results of creep tests on molybdenum-bearing and molybdenum-free heat-resisting steels are discussed. It is no longer necessary to alloy steels for use at up to 400° C. with molybdenum, as experience has shown certain manganese, silicon, chromium–manganese, and chromium–vanadium steels to have adequate creep strength.

**Steels and Alloys Developed for Use at Elevated Temperatures in Petroleum Refineries as Still Tubes and Other Parts.** B. B. Morton. (Transactions of the American Society of Mechanical Engineers, 1942, vol. 64, pp. 113–119.) A review.

**Alloy Steel for High Temperature Service. II. Their Properties Compared.** R. F. Miller, G. V. Smith, and P. A. Jennings. (Metals and Alloys, 1942, vol. 16, pp. 881–885). A graphical presentation of thermal condition of several steels from room temperature to 816° C., susceptibility to oxidation in air, hardness of air-cooled steels and influence of composition on creep and tensile strength at 538° C., on susceptibility to oxidation in air at 927° C. Successful use of metals under stress at elevated temperatures involves appreciation of the fact that, in many ways, their behaviour is fundamentally different from that at room temperature.

**The Cyclic Temperature Acceleration of Strain in Heat-Resisting Alloys.** G. R. Brophy and D. E. Furman. (Transactions of the American Society for Metals, 1942, vol. 30, pp. 1115–1130).

**The Diagram of Nitrogen-Containing Chromium and Chromium–Manganese Steels.** H. Krainer and O. Mirt. (Archiv für das Eisenhüttenwesen, 1942, vol. 15, pp. 467–472). Austenitic chromium–manganese steels containing nitrogen have higher elastic limits and elongation and higher strength at high temperatures and creep strength than nitrogen-free steels.

**A New Alloy for Working at High Temperatures.** P. H. Brace. (Metal Progress, 1942, Mar., pp. 354–360). An alloy, designated K.42.B, containing 40–50% of nickel, 20–30% of cobalt, 1–4% of titanium, 5–15% of iron, and 15–30% of chromium, has been developed to give high resistance to oxidation at high temperatures, high tensile strength and a satisfactory balance between other properties such as ductility, workability, corrosion resistance, and response to heat-treatment. Properties at atmospheric temperature and at 600° C., respectively, are : tensile strength 73·5 and 56·7 tons/sq. in. ; elastic modulus 29,000,000 and 25,000,000 lb./sq. in. ; elongation 29 and 21·5%, these figures being obtained after a heat-treatment consisting of heating for 2 hr. at 950° C., quenching, and reheating at 650° C. for 72 hr.

**Heat-Resisting Steels.** (Engineer, 1942, vol. 173, June 12, pp. 499–501). As the chromium content increases the limiting temperature, up to which resistance to scaling is maintained, rises to 1,200° C. Nickel in quantities greater than 25% increases the resistance to scaling. In amounts less than 25% the function of nickel is mainly to increase the amount of austenite present and raise the strength at high temperatures. Manganese of 18% acts in a similar way to a nickel content of below 25%. As a means of obtaining a high proportion of austenite, nitrogen must now be considered and very probably, in future, great importance will be attached to the nitrogen-bearing heat-resisting steels. The ferritic heat-resisting steels include the chromium, chromium–silicon and chromium–silicon–aluminium steels. The ferritic chromium–aluminium steels containing 20% to 30% of chromium and 3% to 8% of aluminium are used almost exclusively for electrical heating elements. At high temperatures the austenitic steels show a great advantage over ferritic steels in resistance to creep. Exposure of the austenitic chromium–nickel steels to temperatures of 600° to 900° C. produces an embrittling effect dependent on composition.

**The Properties of Austenitic Valve Steels which are Alloyed with Manganese.** H. Cornelius. (Luftfahrt Forschung, 1942, vol. 19, p. 44 : Chemisches Zentralblatt, 1942, II, p. 95). Results are reported on steels containing carbon 0·23–0·55%, chromium 13–20%, nickel 4·2–13%, aluminium 0–2·4%, manganese 0·7–6·8%, silicon 1·5–4·3%, vanadium 0–1·1%, and tungsten 0–2·4%. The nitriding ability was tested for these steels and for others containing carbon 0·1–0·95%, chromium 15–18%, nickel 0·6–15%, copper 0–1·7%, manganese 0·7–9%, molybdenum 0–2·2% and columbium plus tantalum 0–1·0%. It is suggested that the chromium–nickel–manganese–tungsten steels are as suitable for valve steels as the usual chromium–nickel–tungsten steels.

**Effect of Titanium on the Creep Strength of Steel.** P. Bardenheuer and W. A. Fischer. (Archiv für das Eisenhüttenwesen, 1942, vol. 16, pp. 31–38). When adding titanium to steels with 0·05–0·2% of carbon a maximum of creep strength was found, after quenching from 1200° C. in water and drawing to 600° C., at 500°, at a titanium/carbon ratio of 6 to 9.

**Strategic, Especially Low-Nickel and Nickel-Free, Austenitic Exhaust-Valve Materials.** W. Tofaute and G. Bandel. (Technische Mitteilungen Krupp, Forschungsberichte, 1942, vol. 5, pp. 192–200.) The most common and generally satisfactory material for exhaust valves has so far been an austenitic steel (WF 100) with chromium 15%, nickel 13%, tungsten 2%, and carbon about 0·5%. It was found, however, that reducing tungsten to 1% and replacing it by the same amount of molybdenum, tantalum–columbium and/or vanadium does not impair the properties. The scaling-resistance of the chromium–managanese steel is somewhat lower than in the corresponding chromium–nickel alloys.

**A Method of Testing the Scaling-Resistance of Heat-Resistant Alloys.** L. Wetternik. (Korrosion and Metallschutz, 1942, vol. 18, Apr., pp. 130–134). An apparatus is described by means of which a scaling test can be employed under accurately definable conditions. In addition a method for the removal of scale from the sample is described, by which there is no serious attack on the basic metal.

**The Equilibrium Diagram of the Iron–Nickel–Aluminium System.** W. Dannöhl. (Archiv für das Eisenhüttenwessen, 1942, vol. 15, No. 7, pp. 321–330). The equilibria in the iron–nickel–aluminium system, based on thermal and micrographic investigations, are shown in ternary diagrams for 20°, 600°, 700°, 850°, 1150° C. and immediately after solidification ; binary diagrams for the Fe–NiAl section and for sections with constant aluminium contents of 5%, 7·5%, 10%, 12·5%, and 15%, and with constant nickel contents of 10%, 20%, 30%, 40%, 50%, and 60%, are also given.

**The Effect of Thorium in Electrical Resistance Heating Alloys.** E. W. Frölich and A. Barthel. (Metallwirtschaft, 1942, vol. 21, Feb. 20, pp. 103–5). Graphs are presented to illustrate the effect of varying additions on the life of 80/20 nickel–chromium alloy wire at 1150° C. and at 1250° C. and of aluminium–chromium–iron alloy wire at 1250° C. Small amounts of thorium have a markedly beneficial influence and maximum improvement is obtained with additions of the order of 0·1–1%. Larger additions confer no greater improvement, and with thorium at 2% the life curve begins to fall.

**Tables of Data on Chemical Compositions, Physical and Mechanical Properties of Wrought Corrosion-Resisting and Heat-Resisting Chromium and Chromium-Nickel Steels.** R. Franks and F. L. Laque. (American Society for Testing Materials, Brochure, Dec., 1942).

**Balancing the Composition of Cast 25 per Cent. Chromium–12 per Cent. Nickel Type Alloys.** J. T. Gow and O. E. Harder. (Transactions of the American Society for Metals, 1942, vol. 30, pp. 855–935). A ternary diagram is developed to show the phases present in these alloys, and nomographs are presented which show the variations in carbon, chromium and nickel required for wholly austenitic structures. The effect of carbon, nitrogen and carbon plus nitrogen was studied, and for aged specimens the elongation was found to decrease directly as the value of C + N/2 increased, whilst the yield strength increased directly with increasing value of C + 2N.

**Elimination of the Apparent Hot Brittleness of 0·50 Molybdenum Steel.** C. L. Clark and J. W. Freeman. (Transactions of the American Society for Metals, 1942, vol. 30, pp. 1284–1302). The authors present the results of long-time rupture tests on specimens of 0·50% molybdenum steels at temperatures in the 510–760° C. range. These show that this steel fails with a brittle fracture at certain temperatures, particularly 510° and 540° C. The effect of the addition of other alloying elements on the tensile properties of this steel is then considered, and it is shown that this hot-brittleness can be eliminated by the addition of chromium, or chromium plus silicon, but not by silicon alone. The addition of these elements also increases the tensile strength. The low ductility of this steel is believed to be associated with intergranular cracking, but intergranular fractures do not necessarily imply low ductility.

**The Scattering in the Determination of the Creep Strength of Steel in the Air Furnace..** H. Esser, S. Eckardt and G. Finke. (Archiv für das Eisenhüttenwesen, 1942, vol. 16, pp. 1–20). In reviewing the question of what scattering has to be contended with in determining the creep strength by the DVM method, it is found as the result of renewed tests that the percentage scattering found for the creep strength values is not uniform. Comparisons were made at different places and with different testing methods. The one-hour test in stages seems to be suitable for a rapid test of creep strength.

**Testing the Relationship between the Creep Strength and the Heat-Treatment and Cold-Work of Thin-Walled Tubes.** H. Esser, S. Eckhardt and G. Lautenbusch. (Archiv für das Eisenhüttenwesen, 1942, vol. 16, Oct., pp. 131–135). A suitable form of specimen for creep-testing thin-walled tubes by the German standard method A 117/118 at 500° C., was developed. Details of the specimen and of test data obtained after various heat-treatments are presented and discussed. The steel contained 0·15% of carbon and 0·3% of molybdenum. After 27% cold-reduction in manufacture and no heat-treatment the creep strength was 23 kg./sq. mm. Tempering at 650° C. raised this to 25 kg./sq. mm. Raising the annealing temperature to the normalizing temperature reduced the creep strength to 15 kg./sq. mm. Raising the annealing temperature still further to 1050° C. caused a recovery of the creep strength to 23 kg./sq. mm.

**Heat-Resistant Steel.** H. Kalpers. (Österreichische Chemiker Zeitung, 1942, vol. 45, pp. 60–61). A review.

**The Brittleness of Heat-Resistant Steels and Its Influence on the Elastic Properties.** A. Thum and K. Richard. (Archiv für Warmewirtschaft, 1942, vol. 23, pp. 179–182). In chromium–molybdenum steels with small vanadium content, an increase in the carbon content up to 0·3% has a favourable effect.

**Advantages of the Relaxation Method for Studying the Creep of Steel at Elevated Temperatures.** P. Chevenard and X. Wache. (Comptes Rendus, 1942, vol. 215, pp. 437–439). Attention is called to the relaxation method (load for constant specimen length and temperature as a function of time). Advantages of the method are : (1) It gives a direct answer to some practical questions, as in design of bolts for use at elevated temperatures ; (2) it is the best way to study the rate of flow at any given temperature as a function of load ; (3) it is a valuable means for study of the stability in service of steels with high strength at elevated temperatures, as every modification causing a volumetric change affects the curve.

**Heat Resisting Alloy Steels.** C. K. Lockwood. (Canadian Metals and Metallurgical Industries, 1943, vol. 6, Feb., pp. 14–19). The author reviews the properties of heat-resisting alloy steels, classifying them in the following groups : (1) 4–6% chromium steels ; (2) 12–14% chromium steels ; (3) 16–18% chromium steels ; (4) 25–30% chromium steels ; (5) 18/8 chromium–nickel steels ; (6) 25/12 chromium–nickel steels ; and (7) 35/15 nickel–chromium steels.

**Creep Resistance of Superheater Tube Steels in Tube and Bar Form.** J. A. Jones and W. E. Bardgett. (Engineer, 1943, vol. 176, July 2, pp. 6–8). Provided the tubes are produced by a satisfactory method and heat-treated under properly controlled conditions, the application of results of creep tests on bar material to tube design introduces a factor of safety of 25% in the case of a chromium–molybdenum steel for a creep rate of $10^{-7}$ in. per in. per hr. The creep-stress figure for a 0·5% molybdenum steel in bar form may be taken as directly applicable to the corresponding tube material.

**The Development of Heat-Resisting Qualities of Cast Steel Low in Elements in Short Supply.** R. Schinn and R. von Tinti. (Stahl und Eisen, 1943, vol. 63, Feb. 18, pp. 125–133 ; Feb. 25, pp. 151-153). Test on the effects of the alloying elements manganese, chromium, silicon, vanadium, titanium and columbium showed that manganese and chromium increased the creep strength slightly. Silicon had only a limited effect at low temperatures. Vanadium, titanium and niobium greatly increased the creep strength. The most suitable forms of heat-treatment are discussed.

**Fatigue Diagram for Steels at High Temperatures.** M. Hempel and H. Krug. (Archiv für das Eisenhüttenwesen, 1943, vol. 16, Jan., pp. 261–268). Fatigue curves were constructed from tests at up to 500° C. on three heat-resisting steels (a chromium–molybdenum steel, a 13% chromium steel and a 0·51% molybdenum steel.) The machine was a hydraulic pulsator which permitted the free elongation of the specimen during application of the load to be measured. The elongation was measured optically at 200 and at 400 magnifications.

**The Relationship between Load and Rate of Elongation in Creep Tests.** F. Sauerwald. (Archiv für das Eisenhüttenwesen, 1943, vol. 16, Jan., pp. 269–272). The curves for the stress/elongation-rate relationship for various metals are discussed, with special reference to the position of the knee when the logarithmic scales are used. There is a distinct knee in the curves for the most important metals, such as steel, lead, aluminium, magnesium, copper, and tin, the position of which is a measure of the creep strength.

**Notes on the Properties of Carbon Steels Used in Pipe Manufactured for Elevated Temperature Service.** E. C. Wright. (Metal Progress, 1943, vol. 44, Dec., pp. 1127–1130). Fine-grained steels killed with silicon–aluminium, or with aluminium alone, are superior for tubes for service at temperatures up to 850° F.

**Multi-Specimen Testing Equipment for Long-Time Creep Tests.** A. Thum and K. Richard. (Archiv für das Eisenhüttenwesen, 1943, vol. 17, July–Aug., pp. 29–33). The design of two vertical electric furnaces with special holding and testing mechanisms for the creep-testing of up to 400 specimens simultaneously is described in detail.

**The Deformation and Strength of Metallic Materials under Creep Stress.** A. Thum and K. Richard. (Zeitschrift des Vereines Deutscher Ingenieure, 1943, vol. 87, Aug. 21, pp. 513–520). The literature on the short-time and long-time creep testing of metals is reviewed.

**Improved 12 per cent. Chromium Steel Containing Molybdenum.** (Metals and Alloys, 1943, vol. 18, July, pp. 55–62). A report on the effect of additions of molybdenum and silicon to 12% chromium steel is presented. Room-temperature tests on bars containing 0·5%, 1·0%, 1·5%, and 2·0% of molybdenum revealed that the steel with 1% of molybdenum had the best tensile properties. The molybdenum-treated steels had no tendency to temper brittleness. The effect of increasing the silicon from 0·34% to 1·10% in the 1% molybdenum 12% chromium steel was also studied. The increase in silicon had no detrimental effect on the strength properties of the steel in short-time tests at 537–704° C.

**The Properties of Thorium-Bearing Heat-Treatable Steels.** H. Cornelius. (Archiv für das Eisenhüttenwesen, 1943, vol. 17, July–Aug., pp. 23–27). An investigation of the effect of additions of thorium to three low-alloy steels (alloyed with vanadium, chromium and molybdenum, respectively) and one plain carbon steel, all containing about 0·3% of carbon and about 1·8% of manganese, is described. The effect of the insolubility of thorium carbide in solid iron is that the steel loses its heat-treatability entirely if the thorium content amounts to about ten times the carbon content and is sufficient to convert all the carbon into thorium carbide. The presence of large amounts of thorium carbide in heat-treated steel reduced its toughness. The scaling-resistance of the steels at 650° and 800° C. was not improved by the addition of thorium. If the thorium addition exceeds a few tenths of 1% the effect is likely to be detrimental.

**Effect of Deoxidation Practice on Creep Strength of Carbon–Molybdenum Steel at 454° and 537° C.** R. F. Miller. (Transactions of the American Society of Mechanical Engineers, 1943, vol. 65, pp. 309–314). When steels with similar microstructures were compared, that with a low aluminium content had a slightly higher hardness and lower strength than the high-aluminium steel, and the former steel was more creep-resistant at 537° C. under stresses less than 12,000 lb. per sq. in. than the latter. The former steel also exhibited a more pronounced decrease in creep rate with time than the latter.

**Creep of Metals at Elevated Temperatures—The Hyperbolic-Sine Relation between Stress and Creep Rate.** P. G. McVetty. (Transactions of the American Society of Mechanical Engineers, 1943, vol. 65, pp. 761–767). Evidence is submitted to show that the commonly used straight-line relation in the log-log plot becomes unreliable when extrapolated over a considerable range into the field of low stresses.

**Creep Phenomena in Steel at Room Temperature.** A. Pomp and A. Krisch. (Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung, 1943, vol. 26, No. 5, pp. 59–69). The results of room-temperature creep tests on six unalloyed steels, three chromium–nickel–molybdenum steels, a 14·8% chromium steel and an 18/8 chromium–nickel steel are reported. With one of the unalloyed steels the creep fell to zero within 5 hr. (as far as could be ascertained with the apparatus used), but with the other unalloyed steels creep continued for almost 100 hr. With the low-alloy steels and one austenitic steel creep continued after several hundred hours. In some cases creep continued right up to fracture.

**Hyperbolic Sine Chart for Estimating Working Stresses of Alloys at Elevated Temperatures.** A. Nadai and P. G. McVetty. (Proceedings of the American Society for Testing Materials, 1943, vol. 43, pp. 735–745). A method of plotting results of creep tests in a manner which departs from the usual double-logarithmic scales of stress and minimum creep rate is described. The method is based upon the hyperbolic sine function for expressing the dependence of the rate of flow on the stress. The new chart enables available creep-test data to be surveyed in an easily comparable form. Examples illustrate its application to a variety of materials to obtain estimates of stresses for low specific creep rates.

**Interpretation of Creep Test Data.** P. G. McVetty. (Proceedings of the American Society for Testing Materials, 1943, vol. 43, pp. 707–727). The interpretation of creep-test data is based upon the relations between temperature, stress, deformation and time, and the effects of stress and temperature upon the deformation-time ratio are considered.

**The Influence of Temperature on the Modulus of Elasticity of Some Plain Carbon and Alloy Steels.** G. C. Seager and F. C. Thompson. (Journal of the Iron and Steel Institute, 1943, No. 1, pp. 103P–119P). The variation of Young's modulus with temperature has been measured for a series of steels, both plain carbon and alloyed, using an interferometer of high sensitivity. It is shown that the curves are not smooth but have abnormalities which just exceed the experimental error.

**Influence of Strain Rate on Strength and Type of Failure of Carbon–Molybdenum Steel at 454, 537 and 593° C.** R. F. Miller, G. V. Smith and G. L. Kehl. (Transactions of the American Society for Metals, 1943, vol. 31, pp. 817–845). The authors describe a tensile-testing machine with which specimens can be tested to fracture at a selected uniform rate of strain at any desired temperature, and report the results of tests on pearlitic and spheroidized carbon–molybdenum steel.

**Development of Austenitic Manganese-Alloyed Steels for Aero-Engine Exhaust Valves.** D. W. Rudorff. (Metallurgia, 1943, vol. 27, Apr., pp. 205–209). An account is given of an investigation, reported by H. Cornelius in Luftfahrtforschung, 1942, vol. 19, No. 2, p. 44, of German research on the relative merits of austenitic chromium–manganese–nickel steels and austenitic chromium–nickel steels for aero-engine exhaust valves. A 15/13/2 chromium–nickel–tungsten steel with 0·74% of manganese was taken as a basis and its properties were compared with those of 14 other chromium–nickel steels containing up to 8·86% of manganese. Tensile, impact, hardness, wear-resistance, scaling, nitriding, and creep tests were carried out. The partial replacement of nickel by manganese had no adverse influence upon the scaling properties of the steel tested. The divergence of the hardness values of all the steels at room temperatures decreased considerably with increasing temperature in tests at up to 900° C. Tungsten can safely be replaced by vanadium without impairing the creep strength, but the vanadium content should not be more than 0·5–0·6% because of its adverse effect on the scaling. The general conclusion was that a material containing carbon 0·42–0·52%, silicon 1·5–2·0%, manganese 3·0–5·0%, nickel 6·0–4·5%, chromium 17·5—18·5%, and tungsten 0·9–1·3% should prove a very satisfactory valve steel.

**Effect of Tungsten, Molybdenum and Vanadium in Chromium-Containing Heat-Resisting Steels.** R. Hohage, W. Völker and R. v. Tinti. (Archiv für das Eisenhüttenwesen, 1943, vol. 17, pp. 57–64). The effect of tungsten (1–12%), molybdenum (0·5–5%), and vanadium (0·2–1%) in a steel of 0·25–0·3% carbon and 1·5% chromium was investigated. The elastic limit was determined at 400° C., Brinell hardness at 650° C., resistance against hot-cracking at 600–650° C., and heat condition at 400° and 500° C. Tungsten makes steels highly resistant to hot-cracking. Vanadium produces high mechanical strength at high temperature. The heat condition is lowered by alloy content. As a substitute material for tungsten-containing steel a low-alloy chromium–molybdenum–vanadium steel can often be used.

**Creep-Resistant Alloy Steels.** S. E. Wolfson and M. P. Myahkov. (Stal, 1943, Nos. 3–4, pp. 42–47 : Iron Age, 1945, vol. 156, Aug. 2, pp. 58–63). The results of tensile and creep tests at temperatures up to 600° C. on the following alloy steels are presented : (1) silicon steels, (2) chromium–molybdenum steels, (3) chromium–nickel–molybdenum steels, (4) chromium–manganese–silicon–molybdenum steels, (5) chromium–vanadium steels, and (6) chromium–molybdenum–vanadium steels.

**The Effect of the Microstructure as Affected by the Heat-Treatment and Alloying Elements on the Creep Strength of Steel.** H. Bennek and G. Bandel. (Stahl und Eisen, 1943, vol. 63, Sept. 9, pp. 653–659 ; Sept. 16, pp. 673–684 ; Sept. 23, pp. 695–700). An increase in grain-size is not the sole direct cause of improvement in creep strength. In plain carbon steels the effect on the creep strength is due to a precipitation phenomenon the exact mechanism of which has not yet been explained. Tests with heat-treated low-alloy steels showed, contrary to expectation, that those with intermediate structures, even after tempering at far above the creep-test temperature, always had a higher creep strength at 500° C. than those with a tempered martensitic structure. The steels with the softer ferrite–pearlite structure were, generally speaking, considerably lower in creep strength. In order to obtain the optimum structure by transformation in the intermediate stage it is necessary to determine and apply the correct cooling velocity for the section and grain-size of the particular steel. A bibliography of 88 references is presented.

**Structure and Creep Characteristics of Cast Carbon-Molybdenum Steel at 510° C.** H. E. Montgomery and J. Urban. (Proceedings of the American Society for Testing Materials, 1943, vol. 43). The best resistance to creep to 510° C. and 12,000 lb./sq. in. is shown by material having a coarse-grained acicular structure.

**Economizing on Alloy Metals in Heat- and Corrosion-Resisting Cast Alloys.** F. Rubensdorffer. (Chemische Technik, 1943, vol. 16, pp. 65–67). To conserve chromium, nickel, molybdenum, and tungsten, many changes in the composition have been made and vanadium and silicon are being used as partial substitutes. The results are tabulated.

**The Effect of Nitrogen on the Properties of Certain Austenitic Valve Steels.** H. Cornelius and K. Fahsel. (Luftfahrtforschung, 1943, vol. 20, No. 7, pp. 210–216). Valve steels commonly employed contain about 15% of chromium, 13% of nickel and 2% of tungsten. Recently austenitic chromium–manganese steels of much smaller nickel content have been proposed and it was claimed that such steels could be still further improved by small additions of nitrogen. From the results of their investigation the authors conclude that the stabilizing effect of nitrogen is very small and that it does not render possible any marked deduction in the nickel content. The maximum possible addition of nitrogen is 0·25% which is equivalent to about 2% of nickel but in most cases considerably less (about 0·5%) and at this temperature the nitrogen produced only a very small effect. The D.V.L. creep test was carried out at 700° C. For high rates of deformation (pendulum test) the addition of nitrogen is definitely beneficial at temperatures up to 400° C. At 850° C. however, nitrogen appears to have no effect. Tests carried out on scale formation, thermal conductivity and thermal expansion all showed that the nitrogen content exerts a very minor influence.

**Fatigue Diagrams for Steel at High Temperatures.** M. Hempel and H. Krug. (Archiv für das Eisenhüttenwesen, 1943, vol. 16, Jan., pp. 261–268). Fatigue curves were constructed from tests at up to 500° C. on three heat-resisting steels (a chromium–molybdenum steel, a 13% chromium steel and a 0·51% molybdenum steel). The machine was a hydraulic pulsator which permitted the free elongation of the specimen during application of the load to be measured. At temperatures above 300–400° C. the Wöhler method was not satisfactory because of the non-uniform elongation. For this reason the results were evaluated from the maximum elongation rates and the permanent elongation. In this way, two different limits to the fatigue diagram for each steel were found. These limits enclose a region in which the elongation rate or the permanent deformation lie within permissible limits. The testing of the steels in question led to three characteristic limiting cases having fundamental differences in the shape of the fatigue curves. The suitability of a steel to withstand alternating stresses at high temperatures should be judged from both short-time static tests and the elongation in tensile-fatigue tests.

**Influences of Notches at Room Temperature and Elevated Temperatures on High-Temperature Austenitic Steels.** H. Cornelius and W. Schmidt. (Luftfahrtforschung, 1943, vol. 20, pp. 292–296 : Chem. Abs., 1944, June 10, p. 2607). Tensile tests and tensile-fatigue tests were made at 20°, 450° and 600° C. on steels with the following compositions : (*a*) Carbon 0·12%, silicon 0·80%, manganese 0·70%, nickel 9·3%, chromium 17·9%, tungsten 0·93%, tantalum + columbium 1·8% ; (*b*) carbon 0·12%, silicon 0·92%, manganese 0·71%, nickel 29·2%, chromium 15·3%, titanium 1·6% ; (*c*) carbon 0·06%, silicon 0·65%, manganese 0·85%, nickel 36·2%, cobalt 22·8%, chromium 13·7%, molybdenum 4·4%, and tungsten 4·9%. Steel (*a*) when annealed at 800° C. and air-cooled was stronger in all cases than the same steel subjected to the same procedure at 1050° C.

**The Variation of the Strength, Resistance to Oxidation and Electrical Conductivity of Metals with Temperature.** D. J. McAdam, jun., and G. W. Geil. (Transactions of the American Society for Metals, 1944, vol. 33, pp. 514–534). Additional evidence is presented that the strength of metals varies linearly with temperature as measured on Kelvin's original thermodynamic scale. Diagrams derived from data in the authors' previous papers show that the logarithm of the oxidation time is linearly related to temperature expressed on the above scale. From data in the literature it is seen that the logarithm of the electrical conductivity increases nearly linearly with decreasing temperature (on the above scale) from the melting point down to the temperature of liquid air, and sometimes to a point almost as low as the temperature of liquid hydrogen. This evidence, when considered in conjunction with the theory of interatomic forces, suggests that the strength of metals continues to increase when the temperature decreases far below that of liquid air.

**Creep Properties of Steel Utilized in High-Pressure and High-Temperature Superheater and Steam-Pipe Practice. Part I. Carbon Steels.** H. J. Tapsell. (Proceedings of the Institution of Mechanical Engineers, 1944, vol. 151, pp. 54–62). Creep tests are reported on carbon steels used in superheater tubes and steam pipes for service at temperatures up to about 480° C. The object was to obtain data for the estimation of the stress-temperature relationships for specific creep strains of 0·1–0·5% to occur in 100,000 hr. and these were obtained with sufficient precision to warrant their acceptance for practical purposes.

**Gas Turbines.** T. Hamilton-Adams. (Iron and Steel, 1944, vol. 17, Mar., pp. 284–294). Some alloys capable of resisting the attack of gases at 1500° C. which might be used for gas-turbine construction are discussed. One of these contains chromium 33·3%, molybdenum 30·8%, and iron 35·9%.

**Gas Turbines.** (Iron and Steel, 1944, vol. 17, May, pp. 365–366). Data are presented on the properties of alloy steels suitable for high-temperature service in gas turbines. These are classified in two groups, one for use at temperatures up to 550° C. and the other for higher temperatures. The first group includes steels containing 0·75–1·0% of molybdenum and up to 1·5% of chromium, and steel containing 7–15% of chromium with or without marked quantities of silicon. In the second group are the steels containing 18% min. of chromium and 8% min. of nickel.

**High Temperature Alloys for Dynamic Loading.** C. T. Evans, jun. (Iron Age, 1944, vol. 153, June 1, pp. 38–41). Factors to be considered in the selection of alloys for use in new war weapons such as the jet-propelled aeroplane are briefly analysed. Methods of graphically presenting the results of tensile and creep tests at increasing temperatures and their application in the selection of alloys for high-temperature service are explained.

**Developments in Corrosion and Heat-Resisting Steels.** L. Sanderson. (Engineering and Boiler House Review, 1944, vol. 58, Dec., pp. 308–310). An account is given of some war-time developments in corrosion and heat-resisting steels. When columbium is added to 18/8 stainless steel its creep resistance at 600° C. is considerably increased, whilst titanium has little effect. The strength at high temperatures of fine-grained steels killed with silicon–aluminium is greater than that of steels killed by other methods.

**The Scaling Behaviour of Hard Alloy Welded Deposits with Different Cobalt Contents.** H. Cornelius. (Stahl und Eisen, 1944, vol. 64, Aug. 17, pp. 529–532: Iron and Steel Institute, Translation Series, No. 250). In air, welded deposits containing 1–36% of cobalt behaved just the same as alloys containing 60–65% of cobalt. Alloys with 30–36% of cobalt having equal scaling resistance to the exhaust gases from both leaded and non-leaded petrol can be prepared, the cobalt being replaced by iron and the other elements remaining approximately the same.

**Graphitization Caused by Testing Conditions on Carbon–Molybdenum Tubular Creep-Test Specimens.** H. J. Kerr and F. Eberle. (Transactions of the American Society of Mechanical Engineers, 1944, vol. 66, p. 1). The results of an examination of tubular specimens of 0·5% molybdenum steel after they had been submitted to creep tests to 482° C., and for 14,250 hr. at 565° C., special attention being given to the degree of graphitization.

**Carbide Instability of Carbon–Molybdenum Steel Piping.** R. W. Emerson. (Transactions of the American Society of Mechanical Engineers, 1944, vol. 66, pp. 5–15). An investigation of the cause of failure of a weld in a steam pipe of molybdenum steel is reported. The failure was due to the precipitation of graphite in the parent metal at the edge of the heat-affected zone. The theory is put forward that using liberal quantities of aluminium to deoxidize the steel adversely affects the stability of the carbides.

**Bursting Tests of Steam Turbine Disc Wheels.** E. L. Robinson. (Transactions of the American Society of Mechanical Engineers, 1944, vol. 66, pp. 373–380). Bursting tests on model discs of steam-turbine rotor material show that the average hoop stress at bursting speed for a good alloy steel is likely to exceed its tensile strength. Test results on low-carbon and high-alloy steels are included.

**A Possible Means of Avoiding Local Graphitization of Steels in Service at Elevated Temperatures.** G. V. Smith and R. F. Miller. (Transactions of the American Society of Mechanical Engineers, 1944, vol. 66, p. 17). A theory based on the possibility of different types of carbide existing in the same steel, is put forward to explain the graphitization of molybdenum steel which occurs occasionally in the heat-affected zone of welds in high-temperature steam pipes of this steel. During welding, that portion of the pipe which later graphitized, reached about 730° C. and caused austenite to form. This austenite, having formed at just above the eutectoid temperature, is rich in carbon and transforms on subsequent cooling, at a lower temperature than would the austenite of the composition of the pipe as a whole; it may, therefore, form carbide of the $Fe_3C$ type, not $(Fe,Mo)_3C$. As the former is not so stable as the latter, graphitization is likely to take place where the former is precipitated.

**Report on High-Temperature Pipe Weld Investigation.** H. Weisberg. (Transactions of the American Society of Mechanical Engineers, 1944, vol. 66, p. 19). A molybdenum–steel steam pipe operating at high temperature having failed owing to graphitization, a study was made of the condition of welds in high-temperature steam pipes at other power stations in the United States. Specimens, some stressed at 7 tons/sq. in., and others unstressed, were held at 538° C. for 936 hr.; there was considerably more graphite in the stressed specimens.

**Progress Report on Graphitization of Steam Lines.** S. L. Hoyt and R. D. Williams. (Welding Journal, 1945, vol. 24, May, pp. 274-s–282-s). Investigations on the graphitization of carbon–molybdenum steel pipes used for high-temperature steam, which are being undertaken at the Battelle Memorial Institute, and at university and industrial laboratories are reviewed. Plain carbon steels graphitize more easily than molybdenum steels. After exposing molybdenum steels at temperatures up to 607° C. for 1500 hr., only those which had been deoxidized with a considerable amount of aluminium showed graphitization.

**Notch-Toughness Tests of Carbon–Molybdenum Pipe Materials.** W. F. Kinney, I. A. Rohrig and H. S. Walker. (Transactions of the American Society of Mechanical Engineers, 1944, vol. 66, pp. 421–429). The effect of composition, melting practice and heat-treatment on the microstructure, notch-toughness and other physical properties is studied. The influence of the shape of the specimen and the heat-treatment on the uniformity of the test results and on the magnitude of the average notch-toughness values was determined at room temperature and at 496° C. A survey of the literature is included.

**Correlation of Short- and Long-Time Elevated Temperature Test Methods.** J. S. Worth. (Proceedings of the American Society for Testing Materials, 1944, vol.44, pp. 185–215). The sustained load tension, Hatfield time-yield and DIN (DVM) tests showed the most

promise as means for predicting long-time behaviour and should be further investigated. There are 76 references.

**Metallurgy and Heat Flow Problems in High-Temperature Valves.** G. Gohs and W. E. Heilig. (Steel, 1944, vol. 115, July 3, pp. 90–92). Experiments were carried out to determine the most suitable steel for valves in pipe lines carrying hydrocarbon gasses at 760° C. The design of the valve and thermal conductivity of the steel had to be such that the valve packing would not be heated above 396° C. A 25/12 chromium–nickel steel was found to be the most suitable.

**Behaviour of a Special Heat-Resisting Material in Creep Tests at 620° C.** E. Both. (Zeitschrift für Metallkunde, 1944, vol. 36, pp. 149–52). The paper deals with a material designated "DVL 42 (PMWC + Ti)," which in earlier tests had shown specially promising mechanical properties at temperatures above 600° C. The composition is given as carbon 0·07%, silicon 0·55%, manganese 0·90%, nickel 36·9%, cobalt 24·5%, chromium 14·8%, tungsten 4·8%, molybdenum 5·3%, and titanium 1·3%. The alloy was tested in the form of cold-drawn wire. The tests were made at 620° C. in a modified form of the creep-test apparatus described by Grünert and Rohn.

**The Influence of Small Additions of Thorium on the Life of Electrical Resistance Heating Alloys.** W. Hessenbruch and L. Horn. (Zeitschrift für Metallkunde, 1944, vol. 36, pp. 145–146). A further study was made of the influence of thorium, using alloys containing 20 per cent. of chromium, small amounts of manganese and silicon, and remainder nickel. Additions were calculated to give final thorium contents of 0·05–4·0%, but there was heavy loss of thorium in melting, resulting in a series of alloys containing 0·015% to 2·1%. Results show progressive improvement with rise in thorium content, and there is no indication that the maximum values have been reached at the 2·1% level. Although the use of so high a percentage of thorium would not be practicable, due to deterioration in the working qualities of the alloys, from the point of view of the influence of thorium on the life of resistance alloys, there appears to be no justification for the conclusions drawn by Fröhlich that so low a percentage as 0·2–0·3% represents the maximum useful addition.

**An Emergency Heat-Resistant Alloy.** O. E. Harder and J. T. Gow. (Transactions of the American Society for Metals, 1944, vol. 32, pp. 407–475; discussion pp. 476–482). Approximately 100 alloy compositions were studied. Many data are given for steels within the range of chromium 6% to 24%, nickel 2% to 12%, manganese 0·5% to 15%, silicon 1% to 4%, and nitrogen 0·04–0·08%. The most extensively studied alloy contained carbon 0·35%, chromium 12·3%, nickel 7·8%, silicon 2·28%, and manganese 7·8%. It has adequate strength, ductility, load-carrying capacity and resistance to oxidation at 760° C. and is wholly austenitic.

**Creep Strength Stability of Microstructure and Oxidation Resistance of Cr–Mo and 18-Cr/8-Ni Steels.** R. F. Miller, W. G. Benz and M. J. Day. (Transactions of the American Society for Metals, 1944, vol. 32, pp. 381–400). Investigations of the effect of heat-treatment on the creep strength and stability of microstructure of several chromium–molybdenum and chromium–nickel steels at 1,000° and 1,100° F. over a period of 3,000 hr. showed that at 1,100° F. the creep strength of the former steels is substantially the same over the chromium 2% to 9% range, that the stability of chromium–molybdenum steel (with chromium 5%) is increased by adding titanium or columbium, and that that of 18/8 steel with columbium is greater than that of 18/8 with or without titanium. At 1,700° F. all the carbon–molybdenum and chromium–molybdenum steels were severely attacked.

**The Influence of Heat-Treatment and Microstructure of Austenitic Heat-Resisting Steels on the Scatter of Creep Test Results.** E. Morlet. (Revue de Métallurgie, Memoires, 1944, vol. 41, June, pp. 161–168; Sept., pp. 284–291; Oct., pp. 346–352). The following conclusions were arrived at: (1) In order to limit scatter of the creep-test results, the heat-treatment should be carried out at the following temperatures: Quenching from 1150° C. followed by tempering at 900° C. for 6 hr. (2) A coarse-grained steel possesses a higher creep resistance, and it is possible to represent by a diagram on a logarithmic scale the variation of the creep rate in relation to the number of grains per square millimetre. (3) The scatter of the results is more pronounced in creep tests of long duration, and this shows the superiority of coarse-grained forged steel over a fine-grained rolled steel. (4) The coarse grain, caused by overheating, makes the steel susceptible to intergranular fractures which considerably affect the creep resistance.

**Production Technology and Properties of Steel EI1332. (25–20)** V. S. Kultygin and M. I. Vinograd. (Stal (N.S.), 1944, vol. 4, pp. 235–236). Stainless steel EI1332 contains carbon 0·07–0·15%, silicon not more than 1·50%, manganese not more than 1·50%, chromium 24·0–26·0%, nickel 19·0–21·0%, sulphur not more than 0·030%, and phosphorous not more than 0·030%. It is suitable for parts operating at high temperatures, and under corrosive conditions, *e.g.*, piping and storage tanks for the petroleum industry. The mechanical and physical properties and the optimum treatment were studied. It is recommended that this steel should be forged at 1000–1050°. When properly treated EI1332 steel is heat-resistant up to 1200°.

**The Creep Behaviour of Heat-Resisting Steels at Temperatures from 800–1200°.** E. Siebel and G. Hahn. (Archiv für das Eisenhüttenwesen, 1944, vol. 17, pp. 211–20: Iron and Steel Institute, Translation Series, No. 297). Six steels were examined, three chromium steels with 6%, 16%, and 23% chromium and steels with 5% aluminium, 9% chromium, 1% titanium; 18% manganese, 9% chromium, 1% nickel; and 23% chromium, 18% nickel. The long-time test was made in air. In the test of load required for a total elongation of 1% after 1000 hr. the ferritic steels were superior at 1000° C.; the chromium–manganese steel, at 900° C. If the steel with 16% chromium was previously annealed at 1000° for 500 hr. the time-elongation limit at 900° C. was increased 2·5 times. If fractures occurred they were intercrystalline in the austenitic steels independently of testing temperature and load, and predominantly transcrystalline in the ferritic steels. The fractures of the ferritic steels showed a much greater deformability than those of the austenitic steels. Thirty-nine references are appended.

**Replacing Nickel with Nitrogen in Heat-Resistant Steel.** A. M. Samarin. (Bulletin de l'Académie des Sciences de l'U.R.S.S. Classe. sci. tech., 1944, pp. 54–57: Chem. Abs., 1945, May 20, p. 2047). Hardness increased with increase in nitrogen content and decrease in nickel content. This hardness did not interfere with cold-working of the steel. The hardness decreased on heating at 900° C., and further on heating at 1200° C. This is caused by the oxidation of the grain boundaries. Steel containing chromium approximately 25%, nickel 13%, and nitrogen 0·20–0·25% was fully as good as heat-resistant steel containing chromium 25% and nickel 20%. Such a substitution of nickel by nitrogen produced a pure austenite structure, which was stable after a prolonged heating at 600°, 900° and 1200° C. The steels were resistant to oxidation at high temperatures and their impact strength increased after prolonged heating at 600°, 900°, and 1200° C.

**The Creep Strength of Nickel–Chromium–Cobalt and Iron–Chromium–Cobalt Alloys.** A. Krisch. (Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung, 1944, vol. 27, pp. 1–12). The creep strength of an alloy containing carbon 0·08%, silicon 0·78%, manganese 1·12%, chromium 11·6%, nickel 39·9%, cobalt 20·6%, molybdenum 3·86%, tungsten 3·85%, tantalum 3·60%, remainder iron, was determined at 600°, 700°, and 800° C. The values of the creep strength at 600° C., calculated on the basis of a speed of elongation of $10 \times 10^{-4}$%/hr. for 25–35 hr., are given as 24, 32 and 33 kg./sq. mm. for the annealed, hot-worked, and 30% cold-worked conditions respectively. The values of the creep strength at 70° and 800° C. calculated on the basis of 1% total elongation in 300 hr. and a speed of elongation of $10^{-4}$%/hr. for 1000 hr., are also given. The changes of static mechanical properties following the creep tests have been studied, and the structural changes, taking place during creep are explained by means of a series of micrographs. In addition, the creep strengths of four alloys, having a similar composition to that given above, but containing no nickel, have been determined at 800° C.

**Study of the Effects of Variables on the Creep Resistance of Steels.** H. C. Cross and W. Simmons. (Proceedings of the American Society for Testing Materials, 1944, vol. 44, pp. 161–185). The work on the creep resistance of steel previously reported by H. C. Cross and J. G. Lowther has been continued. Creep tests were made at 454°C. on the silicon-killed steel, a silicon–aluminium killed steel, an aluminium-killed non-ageing steel, a rimmed carbon–molybdenum steel, and on plain carbon and carbon–molybdenum weld metal.

**Correlation of Short- and Long-Time Elevated Temperature Test Methods.** (Proceedings of the American Society for Testing Materials, 1944, vol. 44, pp. 186–215). A study has been made of ten types of short-time creep tests at high temperature on a 0·35% carbon steel and on a 0·16% carbon steel containing 0·53% of molybdenum in order to ascertain whether they could be used to predict the long-time creep behaviour. From a quantitative standpoint the tests could not be used to predict the long-time creep strength accurately and consistently, but several tests showed sufficient promise to warrant further study. All the test methods except the dynamic hot-hardness test, were, however, capable of distinguishing between materials of different long-time creep strength.

**Heat and Corrosion Resistant Steels.** R. W. Jones. (Steel Processing, 1945, vol. 31, Aug., pp. 489–493). The Carnegie-Illinois Steel Corporation has made available complete data of the properties of all heat- and corrosion-resistant steels.

**Strength of Steels at High Temperatures.** (Engineering and Boiler House Review, 1945, vol. 59, Apr., pp. 82–87; June, pp. 144–147). Several recent papers on methods of testing steel at high temperatures are reviewed, and the results of creep tests and fatigue tests at high temperatures are discussed.

**The Liquidus–Solidus Temperatures and Emissivities of Some Commercial Heat-Resisting Alloys.** J. T. Gow, A. De S. Brasunas and O. E. Harder. (American Institute of Mining and Metallurgical Engineers, Technical Publication No. 1838; Metals Technology, 1945, vol. 12, Aug.). The materials studied were commercial grades of chromium–nickel steels of the 26–12 and 16–36 types. Comparison was made between the data obtained on the commercial materials and those reported by Jenkins and co-workers (*see* Journ. I. and S. I., 1937, No.II, p. 187P). for essentially pure alloys of iron, nickel and chromium, at parallel nickel and chromium levels.

**Materials for High Temperature Service.** O. E. Harder. (Metals and Alloys, 1945, Mar., pp. 725–737). A manual intended to serve as a guide in selecting the right materials for application at temperatures above 538° C. by outlining the most common high-temperature-service problems and describing the types and characteristics of the various cast and wrought heat-resisting alloys available for these specific applications.

**Selecting the Proper Heat-Resistant Steel.** R. A. Lincoln. (Iron Age, 1945, vol. 156, No. 19, pp. 74–77). The 28% chromium steel that is ferritic at all temperatures of its normal use resists carburization better than any of the stainless steels. Chromium also increases resistance to atmosphere containing sulphur; with more than 12% chromium and temperature not in excess of 500° C., excessive attack does not occur but nickel must be kept low. To maintain hardness in service between 371° and 482° C. the use of 12% chromium steel containing 3% tungsten is suggested.

**Wrought Heat-Resisting Alloys for Gas-Turbine Service.** C. T. Evans, jun. (Metal Progress, 1945, vol. 48, pp. 1083–1095). The metallurgy involved in the development of high-temperature alloys for gas-turbine service is reviewed. Short-time tensile stress-to-rupture, creep and fatigue data are given for carbon steel, two carbon–molybdenum steels, eleven stainless steels, and Inconel. Further data are to be presented later.

**Metallurgical Problems in Gas Turbines.** J. F. Cunningham. (Metal Progress, 1945, vol. 48, Sept., pp. 484–488). Problems encountered in the construction of the Elliott–Lysholm 2,500-h.p. gas turbine are discussed. A schematic diagram showing the temperatures and materials of construction at the major parts of the plant is included.

**Development of the Internal Combustion Turbine.** T. A. Taylor. (Proceedings of the Institute of Mechanical Engineers, 1945, vol. 153, pp. 409–512. War Emergency Issue No. 12). This issue contains ten lectures delivered at a symposium on the development of the internal combustion turbine. In the tenth lecture, which was given by Dr. Taylor, he dealt with recent developments in materials. The question is discussed under the heads of the principal components for which the provision of suitable materials gave the greatest difficulty.

**Creep Properties of Some Binary Solid Solutions of Ferrite.** C. R. Austin, C. R. St. John and R. W. Lindsay. (American Institute of Mining and Metallurgical Engineers, Technical Publication No. 1837; Metals Technology, 1945, vol. 12, Aug.). This paper describes another investigation of a series on the properties of binary iron alloys (Transactions of the American Society for Metals, 1943, vol. 31, p. 329). One microstructural phase, namely ferrite, was isolated and its creep characteristics were studied in both the unalloyed and alloyed conditions. Commercially pure ferrite possesses a relatively low creep resistance at 426° C. Whilst nickel or silicon in solid solution raises the tensile strength and hardness of ferrite at room temperature, they have only a slight effect in raising the resistance to deformation at elevated temperatures. Cobalt is similarly ineffective in raising the creep strength of ferrite. On the other hand, whilst chromium does not markedly increase the strength of ferrite at ordinary temperatures, it definitely increases the creep strength of ferrite by its presence in solid solution. Manganese and molybdenum in solid solution are ferrite strengtheners and also increase its creep resistance. Increasing the amount of carbon in ferrite progressively increases the creep strength at 426° C., but a similar increase produced by the carbide phase in lamellar distribution does not equal that produced by chromium, manganese or molybdenum in solid solution.

**New Machines for Creep and Creep-Rupture Tests.** M. J. Manjoine. (Transactions of the American Society of Mechanical Engineers, 1945, vol. 67, Feb., pp. 111–116). The paper describes two machines designed in the Westinghouse Research Laboratories, for testing alloys for use in high-temperature furnaces and other applications.

**The Sigma Phase.** F. B. Foley. (Alloy Casting Bulletin, 1945, July, pp. 1–9). The paper comprises a detailed survey of information available to date, on the occurrence of the brittle sigma phase in chromium–iron and nickel–chromium–iron alloys. The supporting bibliography gives reference to the major literature of the subject. The significance of sigma formation, and associated embrittlement is emphasized in relation to the use of heat-resisting nickel–chromium–iron alloys in commercial service and examples are given of the occurrence of sigma in other systems.

**Exhaust Valve Has Special Design and Manufacturing Features.** W. H. Carhart. (Steel Processing, 1945, vol. 31, Nov., pp. 685–90). The article describes methods used for production of a two-piece forged and flash-welded valve. The head of the valve is of 21/12 chromium–nickel steel, and the stem is of S.A.E. 3140 nickel–chromium steel, treated to a Brinell hardness of about 330.

**Influence of Heat Treatment on Hardness and Texture of a Chrome–Silicon Valve Steel.** W. Felix and H. Dinner. (Schweizer Archiv, 1945, vol. 11, Dec., pp. 386–392: Eng. Abs. (Section b.), 1946, July, p. 179). Tests for the breaking strengths of the various specimens are described and recorded.

**Stainless Steels for Turbine Blading.** J. H. G. Monypenny. (Transactions of the Institute of Marine Engineers, 1945, vol. 57, Dec., pp. 129–140, Discussion 140–144). The properties of stainless iron, high-chromium steels, austenitic steels and Monel are summarized and critically discussed in relation to the ability of the respective materials to satisfy the demands of turbine-blading service. Data on corrosion-resistance, physical and mechanical properties at ordinary and at steam temperatures are given. In the latter connection, creep and fatigue properties are considered, as well as short-time tensile properties.

**A Comparison of Some Carbon Steels on the Basis of Various Creep Limits.** A. E. Johnson and H. J. Tapsell. (Proceedings of the Institution of Mechanical Engineers, 1945, vol. 153, pp. 169, War Emergency Issue No. 6). The present report has been prepared with a view to determining whether any relationship exists between the results of the various short-time and long-time creep tests, which will permit the use of short-time tests, not merely as a means of separating good from bad steels, but also as the basis of design stresses intended to give satisfactory performance of the steel over working periods of considerable duration. Indications are given of some of the difficulties and limitations concerned in the use of short-time creep results in the case of carbon steels, and suggestions are made for some rational basis for steps which might be taken to offset these difficulties and limitations in applying the results of short-time tests to an estimation of design stresses.

**Creep Properties of Steels Utilized in High-Pressure and High-Temperature Superheater and Steam Pipe Practice. Part II: 0·5% Molybdenum Steels.** H. J. Tapsell and R. W. Ridley. (Proceedings of the Institution of Mechanical Engineers, 1945, vol. 153, pp. 181. War Emergency Issue No. 6). This report deals with the creep properties of carbon–molybdenum steels in the form of a super-heater header, superheater tube, and steam pipe manufactured for service at temperatures above about 450° C. The investigation was carried out in a similar manner to that described in Part I (*see* Journ. I. and S. I., 1944, No.II, p. 88A) which dealt with carbon steels and, as in the former case, the object was to obtain data for the estimation of the stress/temperature relationship for from 0·1 to 0·5% in various periods up to 100,000 hr. It is considered that the data provide a satisfactory basis for design.

**Heat-Resisting Metals for Gas-Turbine Parts.** H. C. Cross and W. F. Simmons. (Symposium on Materials for Gas Turbines, American Society for Testing Materials. 1946, June 24–28, p. 3). This report shows the results of high-temperature tests on heat-resisting alloys carried out under National Defense Research Committee Project NRC-8 to study and evaluate new alloys. The materials studied ranged from modified 18% chromium, 8% nickel steels to practically iron-free cobalt–chromium and cobalt–chromium–nickel alloys with additions singly or in combination of molybdenum, tungsten, columbium, tantalum, titanium, aluminium, boron, and nitrogen. Short-time tension tests were made on the precision-cast cobalt-base alloys at 538–871° C. Stress-rupture tests were made at 816°, 871°, and 1093° C. to determine the stresses for rupture in times varying from 100 to 1000 hr. Creep tests were made at 732°, 816°, and 871° C. to pick out the better alloys and to determine the stresses required to produce creep rates of 0·00001%/hr. The cast cobalt-base alloys show better stress-rupture and creep properties generally than the forged alloys, except for creep resistance at 732° C. Design curves based on both stress-rupture and creep data at 816° C., show that for low values of total deformation, some of the forged alloys are superior to the cast alloys.

**High-Temperature Alloys Developed for Aircraft Turbo-Superchargers and Gas Turbines.** J. W. Freeman, E. E. Reynolds and A. E. White. (Symposium on Materials for Gas Turbines, American Society for Testing Materials, 1946, June 24–28, p. 52). In recognition of the advantages to be obtained through the use of the gas turbine in aircraft power plants, the National Advisory Committee for Aeronautics started to sponsor research work in November, 1941, to develop suitable heat-resistant alloys. This paper describes the alloys which have evolved from the phase of their work conducted under contracts at the University of Michigan. Due to necessary restrictions under wartime conditions, the results have previously only been given limited circulation. The activities of the NACA in the field of heat-resistant alloys have been directed by a Special Sub-Committee on Metals for Turbosupercharger Wheels and Buckets and its successor the Sub-Committee on Heat-Resisting Alloys. Actually the investigation at the University represents parts of a co-operative effort to develop improved heat-resistant alloys in which the members of the sub-committee extensively utilized the facilities of their companies and organizations to extend the scope of the work.

**Chromium-Base Alloys.** R. M. Parke and F. B. Bens. (Symposium on Materials for Gas Turbines, American Society for Testing Materials, 1946, June 24–28, p.80). This paper describes an investigation of chromium-base alloys, a class of heat-resistant materials not well known. The investigation was supervised during its entirety—for 3½ years—by the War Metallurgy Committee of the National Defence Research Committee, through contract with Climax Molybdenum Co. It was part of a project entitled "Development of Heat-Resistant Metals for Gas-Turbine Parts." In particular, the heat-resistant metals being sought were for use as gas-turbine blades rotating in an oxidizing atmosphere at temperatures up to 870° C. During the final year of the investigation, the alloys

were applied experimentally as erosion-resistant materials for ordnance uses under the supervision of Division One, NDRC.

**Metallurgy of High-Temperature Alloys Used on Current Gas Turbine Designs.** F. S. Badger and W. O. Sweeny. (Symposium on Materials for Gas Turbines, American Society for Testing Materials, 1946, June 24–28, p. 99). This paper outlines the development of the two original groups of alloys, one with a nickel base and the other a cobalt base, which were used, and covers their successful fabrication by forging and by precision casting to meet the wartime mass-production requirements. Metallurgical data not previously published are presented, as well as a discussion of the importance of certain mechanical properties as related to design. An indication of the probable benefits of the new and relatively untried high-temperature alloys, and an outline of what may be expected in the near future from alloys now in the development stages are included.

**Alloys and Ceramic Materials for High-Temperature Service.** H. C. Cross. (Symposium on Materials for Gas Turbines, American Society for Testing Materials, 1946, June 24–28, p. 113). The author discusses a plan of research being carried out at Battelle Memorial Institute under contract with the Office of Research and Inventions, Navy Department. The materials now under test include the following: (*a*) Low-carbon alloy type N-155 (C 0·15%, Cr. 20%, Ni 20%, Co 20%, Mo 3%, W 2%, and Cb 1%); (*b*) type S-590 (C 0·45%, Cr 20%, Ni 20%, Co 20%, W 4%, Mo 4%, Cb 4%); (*c*) type S-816 (C 0·40%, Cr 20%, Ni 20%, Co 45%, W 4%, Mo 4%, and Cb 4%); (*d*) Inconel-X (C 0·05%, Cr 14%, Ni 74%, Ti 2·3%, Al 0·7%, Cb 1·0%, and Fe 7%); (*e*) Refractaloy 26 (C 0·03%, Cr 18%, Ni 37%, Co 20%, Mo 3·1%, Ti 3%, and Al 0·25%; (*f*) S-816 and rolled Vitallium (C 0·25%, Cr 27%, Ni 3%, Co 62%, and Mo 5·5%). The effect of metal pouring temperature has been explored and damping capacity and tension fatigue tests have been carried out. Further, an investigation of fundamental factors promoting high-temperature stress of alloys is being studied. In the general programme for this study, the cobalt–chromium binary system was taken as the starting point. Cobalt-base alloys containing up to 50% chromium, will be prepared and examined by X-ray diffraction, metallographic, dilatometric, magnetic and chemical methods to identify the phases in these alloys. The effect of heat-treatments on the microstructures will be investigated. The temperatures of the epsilon-beta transformation will be determined and compared with those reported in the literature. After studying the binary cobalt–chromium system, alloys with iron, carbon, nickel, molybdenum, and tungsten additions will be made and studied.

**High Temperature Alloys.** N. J. Grant. (Iron Age, 1946, vol. 157, May 23, pp. 42–48; May 30, pp. 50–56; June 6, pp. 77–80; June 20, pp. 60–63). This is a report on three years' intensive research work at the Massachusetts Institute of Technology on heat-resisting high-strength steels. The work had two main objects, first to develop alloys for gas-turbine construction to resist temperatures up to 816° C., and secondly, to discover the effects of nitrogen and carbon on certain nickel–chromium–cobalt–iron alloys. Tables showing the composition and properties of many alloys are presented. The optimum carbon content of the nickel–chromium–cobalt–iron alloys was found to be 1·00–1·20%; in this system the high carbon content improved the strength but lowered the ductility. In the cobalt–chromium–molybdenum alloys the addition of carbon greatly increased the strength with no appreciable loss in the hot-ductility.

**Cobalt-Base High Temperature Alloys.** L. E. Browne. (Steel, 1946, vol. 118, May 27, pp. 88–91, 132). The properties of cobalt–nickel alloys are presented and discussed. These alloys, which were on the secret list during the war, were developed for such applications as gas turbines and superchargers.

**Stress-Rupture Characteristics of Various Steels in Steam at 649° C.** J. T. Agnew, G. A. Hawkins and H. L. Solberg. (Transactions of the American Society of Mechanical Engineers, 1946, vol. 68, May, pp. 309–314). Small specimens of a low-carbon steel, a 0·05% molybdenum steel, three chromium–molybdenum steels, a 12% chromium steel, two chromium–nickel steels, and a chromium–molybdenum–titanium steel were placed in a steam reaction chamber at 649° C. and stressed in tension for periods of from 10 to 7700 hr. Data are presented on time to rupture, elongation, reduction in area, depth of scale, effect of type of flow, and type and angle of fracture. A straight-line relationship was obtained on plotting stress against time using logarithmic scales.

**Super Alloys for High Temperature Service.** H. A. Knight. (Materials and Methods, 1946, vol. 23, June, pp. 1557–1563). Some of the heat-resisting alloy steels developed in the United States for use in turbine and jet aero-engines are discussed.

**Influence of Stress on Creep Failure.** W. Stegfried. (Sulzer Technical Review: Iron and Coal Trades Review, 1946, vol. 152, June 14, p. 1072). The theories advanced by Rosenhain and Ewen, Thum and Richard, and Thielemann, to account for creep failures are reviewed. The logical evaluation of the conceptions developed by Rosenhain and Ewen allows not only various phenomena to be explained which hitherto could not be interpreted, but it also furnishes a basis for determining the risk of failure with creep in a three-dimensional system of stress.

**Velocity-Modified Temperature for Plastic Flow of Metals.** C. W. McGregor and J. C. Fisher. (Journal of Applied Mechanics, 1946, vol. 13, No. 1, Mar.). Expression by single variable of combined effects of strain rate and temperature on stress reaction in tension specimen; velocity modified temperature applicable to tension test at both slow and rapid rates and to creep test; finding stress reaction rates, from tension tests at moderate strain rates and appropriately adjusted temperatures. Bibliography.

**Series II Goblin: Full Details of the Latest de Havilland Turbine-Jet Engine.** (Flight, 1946, vol. 49, Feb. 21, pp. 185–190). Details are given of the materials used in the Goblin engine.

**Resistance-Welding of Heat-Resisting Materials for Aircraft.** H. E. Lardge. (Aircraft Production, 1946, vol. 8, Mar., pp. 107–113). The article is based on work carried out by Messrs. Joseph Lucas, Ltd., in connection with the development of combustion and fuel systems and other components of gas-turbines used for aircraft propulsion.

**16-25-6 Alloy for Gas Turbines.** M. Fleischmann. (Iron Age, 1946, vol. 157, Jan. 17, pp. 44–53; Jan. 24, pp. 50–60). The article describes the heat-resisting steel developed during the war by Timken Roller Bearing Company. The basis of composition for experiment was the 16–13–3 steel (U.S. patent No. 2,118,683) and the requirements of heat-, oxidation- and creep-resistance for temperatures of 650–815° C. The following composition has been developed: Carbon 0·08–0·10%, manganese 2·0% (max.), silicon 1·0% (max.), chromium 16%, nickel 25%, molybdenum 6%, nitrogen 0·15%. The author gives details of the properties of the material, and the structure of the steel in various conditions.

**Aircraft Applications of Resistance-Welded Stainless Steel.** F. G. Harkins and W. L. Hales. (Welding Journal, 1946, vol. 25, Jan., pp. 39–46). A series of examples of specially ingenious applications of spot- and flash-welding used in the assembly of aircraft components.

**High Temperature Steels.** (Iron and Steel, 1946, vol. 19, Apr., p. 159). Some details are given of the progress made by the Germans in solving the problem of providing high-duty steels for gas-turbine work. The development of materials for blading was governed by a design to operate at 550° C. to 600° C. and the D.V.L. at Sonthofen experimented with five different alloys, the composition and test results of which are tabulated. As these did not satisfy the demand for higher creep strength and scale resistance, more highly alloyed materials were developed, and details of three of these are given. The main constituents of these alloys were: Carbon 0·05–0·15%, manganese 0·6–1·5%, silicon 0·5–0·8%, chromium 13–18%, nickel 10–35%, molybdenum 5–7%, tungsten 3–5%, cobalt 25–40%. At the same time Krupps produced the two alloys Tinidur (carbon 0·15% max., manganese 0·2–0·4%, silicon 0·3–0·6%, chromium 14·5–15·5%, nickel 29–31%, and titanium 1·5–1·8%); and Cromadur (carbon 0·12% max., manganese 17·5–18·5%, silicon 0·3–0·6%, chromium 11.5–12.5%, vanadium 0·6–0·7%, nitrogen 0·18–0·23%), the latter being highly inferior in creep properties. The conclusion reached from these examinations is that progress was handicapped by the shortage of alloying materials, which necessitated the use of inferior alloys.

**Drop Forgings for Gas Turbine Application.** C. I. Schweizer. (Materials and Methods, 1946, vol. 24, Sept., pp. 642–645). The parts involved include alloy-steel forgings serving as part of the structural bracing on which stresses are more or less static and fixed; disc-type or rotor-forgings, usually formed of a special alloy possessing high strength at elevated temperatures, in order to withstand high centrifugal stresses caused by speed of rotation; blade forgings, also usually made from special alloys capable of resisting the complex vibratory stresses and centrifugal stresses involved in service.

**Metals for Elevated Temperatures.** (Combined Intelligence Objectives Sub-Committee, File No. XXXII–99, Items 21 and 29). Section I deals with two comparatively short-time creep tests on steels for high-temperature applications. In the first test, of 300 hours duration, results are given as the stress to produce 1% elongation in 300 hr., this standard being designated D.V.L. The second test of 45 hours (D.V.M. test) specifies as a standard the percentage elongation per hour for the period between the 35th and 45th hr. of the test. During this period creep must not exceed 0·001%/hr., and over the 45th hr. the total creep must not exceed 0·2%. Section II deals with alloy steels for boiler construction. These are listed in a table giving their Krupp numbers, composition, physical properties, including creep data, and their applications. Predicted values of the life of the materials from a creep stand-point are also tabulated, these values being taken from a German paper. A list of reference data is appended. Section III presents information obtained at Krupp-Essen regarding certain high-temperature alloys. A table shows the Krupp designation and gives an analysis of the materials concerned. An annotated list of eleven references is given.

**Metallurgical Development of Materials for Turbosuperchargers and Aircraft Gas-Turbines.** W. L. Badger. (Iron Age, 1946, vol. 158, July 25, pp. 40–5; Aug. 1, pp. 60–66). The first part deals with the development from low alloy steels, sil-chrome and 17W types, to the present-day employment of Gamma Columbium, Timken 16–25–6, Vitallium and other heat-resisting materials. The second part of the survey deals with General Electric experience in relation to materials for gas-turbine components. The high-temperature stress-rupture properties of Timken 16–25–6 19–9DL, and modified Inconel (wheel alloys) are compared. Heat-treatment of the respective alloys is discussed and microstructures are illustrated.

**Hardness Testing of Metals and Alloys at Elevated Temperatures.** F. P. Bens. (American Society for Metals, 1946, Preprint No. 3.) The principles of the diamond-pyramid-penetration method of hardness testing have been embodied in an apparatus for determining the hardness of metals and alloys up to 927° C. The apparatus rests on the stage of a standard Vickers machine and employs its loading device and optical system. A vacuum chamber protects the specimen, indenter, and heating element from oxidation. Hardness values are given for chromium, iron, molybdenum, tungsten and some chromium-base alloys from 26·6° to 927° C. and show a fair relationship between hot hardness and stress-rupture strength of stable alloys for periods up to 2000 hours.

**High-Strength, High-Temperature Alloys.** T. Y. Wilson. (Materials and Methods, 1946, vol. 24, pp. 885–890). The strength, hardness, fabrication, and heat-treatment at temperatures up to 816° C. of S-816 alloy, containing cobalt 44%, nickel 20%, chromium 20%, molybdenum 4%, tungsten 4%, and columbium 4%, are given as used for gas-turbine and jet-propulsion developments.

**The Development of a Turbosupercharger Bucket Alloy.** E. Epremain. (American Society for Metals, 1946, Preprint No. 1). The development of alloy X63 is described. Its chemical composition is: Cobalt 57·5%, chromium 25%, nickel 10%, molybdenum 6%, manganese 0·5%, silicon 0·5% and carbon 0·4–0·5%. At 816° C. stress-to-rupture strengths are 15,000 lb. per sq. in. in 100 hr. and 12,500 lb. per sq. in. in 1000 hr.; short-time tensile strength is 70,000 lb. per sq. in.; Charpy impact strength is 25 ft.-lb.; hot-hardness after 1152 hr. exposure is 37 Rockwell C.; creep strength is 2·3% for 100,000 hr. with load of 8,000 lb. per sq. in.; and resistance to oxidation is excellent.

**The Apparent Influence of Grain-Size on the High-Temperature Properties of Austenitic Steels.** C. L. Clark and J. W. Freeman. (American Society for Metals, 1946, Preprint No. 19). The high-temperature properties of types 304, 347, 309 and 310 stainless steels are evaluated on the basis of short-time high-temperature tensile tests, creep strengths, and stress-rupture values at temperatures up to 982° C. In the 304 steel, the coarser-grain structure is somewhat superior at the more elevated temperatures. With the other steels, the finer-grain structures were greatly inferior in their high-temperature-load-carrying ability over certain portions of the temperature range owing to the appearance of an unknown phase but have much higher ductility to fracture under the more prolonged fracture times. For each steel, the choice of the proper grain-size depends upon the proposed operating temperature and the relative importance of strength and hot ductility; a coarse grain structure is preferred when strength is of primary importance.

**Heat-Resisting Steels.** H. Dobkin. (Steel, 1946, vol. 119, No. 18, 78–79, 106–111). High-temperature properties of stainless steels 304, 310, 410, and 430 are given and discussed in terms of chemical composition and heat-treatment.

**The Stress Rupture and Creep Properties of Heat-Resistant and Gas-Turbine Alloys.** N. J. Grant. (American Society for Metals, 1946, Preprint No. 2). Rupture and

creep tests were made with a series of vitallium-base (cobalt–chromium–molybdenum) alloys and nickel–chromium–cobalt–iron alloys at 816–982° C. and stresses of 7,000–15,000 lb./sq. in. for creep strength and of 15,000–35,000 lb./sq. in. for rupture strength to determine the effect of carbon, nitrogen, heat-treatment, and surface conditions of precision cast bars. The higher-carbon alloys are stronger up to a peak carbon value, beyond which strength decreases. Up to 816° C. the vitallium-base alloys have higher rupture strength but lower creep strength than the nickel–chromium–cobalt–iron alloys. At 927° and 982° C., the nickel–chromium–iron–cobalt alloys are superior in both respects. Experimental details and typical photomicrographs are included. Variations in composition include silicon 2–4%, nickel 2–8%, tantalum 2–6%, tungsten 2–8%, beryllium 2%, titanium 2%, and zirconium 2% for the vitallium-base alloys; and manganese 0·4–2%, silicon 0·4–1%, molybdenum 3–6%, tantalum 2–4%, columbium 1–5·3%, tungsten 2·2–4%, and titanium 2% for the nickel–chromium–cobalt–iron alloys.

**Rate of Oxidation of High-Chromium Iron-Chromium-Aluminium Alloys.** I. I. Kornilov and A. I. Spikelmann. (Reports of the Academy of Sciences of U.S.S.R., 1946, vol. 53, Sept. 21, p. 813–816 : Metals Review, 1947, Mar., p. 20). The oxidation process at high-temperatures is assumed to consist of : first, oxidation of the three components ; and second, diffusion of aluminium on the surface of the alloy. To aid in development of high-temperature alloys, a series of high-chromium alloys was invesigated for chemical constitution, weight loss, and changes in electrical properties, after 1000 hr. at 1200° C. Results are presented in chart form. The most heat-resistant combinations found were : 25% of chromium, 7 to 10% of aluminium ; and 40% of chromium, 10 to 13% of aluminium.

**Rate of Oxidation of Chromium-Nickel-Iron Austenitic Alloys.** I. I. Kornilov and A. I. Spikelmann. (Reports of the Academy of Sciences of U.S.S.R., 1946, vol. 54, Nov. 21, pp. 515–518 ; Metals Review, 1947, Mar., p. 20). Ferritic and austenitic heat-resistant alloys, having iron as base metal, are oxidized at elevated temperatures mainly on account of the presence of an easily oxidized element. Experimental results show this element to be aluminium in ferritic chromium–aluminium alloys. In austenitic chromium–nickel alloys containing carbon and silicon, carbon, silicon and chromium are all oxidized readily up to 1100° and 1150° C. Above 1200° C., only carbon and silicon are affected appreciably.

**Changes in Austenitic Chromium-Nickel Steels during Exposure at 595° to 925° C.** P. Payson and C. H. Savage. (American Society for Metals, 1946, Preprint No. 18). The formation of sigma in these steels is promoted by high chromium, high silicon, high nitrogen, low carbon and additions of columbium, titanium and zirconium. As yet no addition or modification has been found to prevent the formation of sigma in the 23 to 25% chromium austenitic stainless steels containing over about 0·5% silicon. However, the presence of high silicon in austenitic heat-resistant steels containing less than about 19·0% chromium apparently does not cause sigma to form even after exposure of about 1000 hr. at 760° or 870° C. The formation of sigma in these steels is generally quite slow. There is usually a precipitation of carbides which precedes and accompanies this formation. The ductility and notch impact resistance of these steels are markedly decreased by these changes.

**Effect of Variations in Composition and Heat Treatment on Some Properties of 4 to 6 per Cent. Chromium Steel Containing Molybdenum and Titanium.** G. F. Comstock. (Transactions of the American Society for Metals, 1946, vol. 36, pp. 81–115). The hardness, tensile properties, notch impact resistance, microstructure, weldability, high-temperature oxidation, and time for rupture under stress at high temperature, are reported for 31 different 5% chromium–molybdenum–titanium steels, some of commercial manufacture and some of special composition melted in the laboratory, heat-treated in several different ways. The effects of variations in manganese, silicon, phosphorus, molybdenum, nitrogen, aluminium, and the titanium–carbon ratio are discussed. It is concluded that titanium–carbon ratios between 3·5 and 5·5 give better properties in general, and especially better notch toughness and high-temperature rupture strength than can be obtained with higher titanium, and such ratios are sufficient for acceptable restriction of air-hardening. Silicon around 1% is very beneficial to the oxidation resistance of this steel, and can be used in the steels with titanium–carbon ratio not over 5·5, without impairing other properties if the manganese content is also raised to about 0·75% or 1%, and the steel is merely tempered at about 730° C. without annealing or normalizing, after hot-working at a reasonably low temperature to produce a fine grain-size.

**Superalloys.** F. S. Badger, H. C. Cross, C. T. Evans, jun., R. Franks, R. B. Johnson, N. L. Mochel, and G. Mohling. (Metal Progress, 1946, July, pp. 97–122). Verbatim report of a round-table discussion at American Society for Metals National Metal Congress and Exposition held in Cleveland, February 5, 1946.

**Increasing the Creep Limit by Cold Work.** H. Zschokke. (Schweizer Archiv, 1946, vol. 12, Oct., pp. 297–304). An investigation is reported in which the effects of changes in the percentage extension and in the creep-test temperature on the creep limit of three 18/8 stainless steels were investigated. The effects of 20% reduction in section by rolling at different temperatures were also studied. The following conclusions were reached : (1) Previous cold extension lowered the creep limit at above 750° C., but at below 400° C. the creep limit was improved ; (2) the creep limit reached a peak in the 400–750° C. range, and then fell sharply ; (3) the maximum improvement brought about by cold extension was noted in the low-temperature creep tests ; in tests at 700° C. there was no improvement ; (4) there was an optimum extension for each creep-test temperature.

**Gas Turbines. Use of Steel under High Temperature Conditions.** C. C. Hall. (Iron and Steel, 1946, vol. 19, Aug., pp. 455–457 ; Sept., pp. 499–501, 505). The metallurgical problems involved in the materials for the modern gas turbine are indicated and data are presented on the properties of steels used in its construction. The blades and disc of the first Whittle engine were made from Firth-Vickers' Stayblade steel. This was ultimately replaced by R.ex 78 steel, the improvement in creep resistance being approximately equal to 100° C. in temperature. Most of the nozzle blades are now produced as precision castings by the " lost wax " process, and Firth-Vickers' H.R. Crown Max steel is used extensively for this purpose. It has excellent castability and good oxidation resistance at temperatures up to 1100° C., while the tensile and creep properties at elevated temperatures are adequate for this purpose. The sheet-metal components have to function under rather onerous conditions of temperature and stress, and while R.ex 78 steel in sheet form has been employed for certain components the steel which has been used mostly for this work is Staybrite F.D.P. steel which conforms to D.T.D. 171B. This steel possesses useful strength properties at elevated temperatures and has a satisfactory resistance to oxidation or scaling up to temperatures of the order of 800 to 850° C. In addition, it is amenable to the various manipulative processes. Another steel

which has been used primarily on account of its scale-resisting properties is Immaculate 5 steel. This is a 25/20 chromium–nickel steel and it has good oxidation resistance up to temperatures of the order of 1100 to 1150° C.

**Studies on Susceptibility of Casting Steels to Graphitization.** J. J. Kanter. (Transactions of the American Society of Mechanical Engineers, 1946, vol. 68, Aug., pp. 581–586). The results, illustrated in photomicrographs, show that aluminium additions to carbon–molybdenum steels cause susceptibility. No evidence of graphitization was found in the steels containing chromium (from 0·43% to 0·70%).

**Comparative Graphitization of Some Low-Carbon Steels with and without Molybdenum and Chromium.** G. V. Smith, S. H. Brambir and W. G. Benz. (Transactions of the American Society of Mechanical Engineers, 1946, vol. 68, Aug., pp. 589–595). Details are given of the graphitization occurring in steels containing 0·5% of molybdenum and up to 1·20% of chromium when they were heated at 550° C. for periods up to 3,000 hr. The tests showed that at least 0·5% of chromium is necessary to prevent graphitization in a 0·5% molybdenum steel, and that more than 0·5% of chromium prevents any graphitization. The addition of varying amounts of aluminium to heats of steels containing 0·1–0·2% of carbon revealed that more than 1lb. of aluminium per ton of steel is necessary before graphitization takes place.

**Further Observations of Graphitization in Aluminium-Killed Carbon-Molybdenum Steel Steam Piping.** R. W. Emerson and M. Morrow. (Transactions of the American Society of Mechanical Engineers, 1946, vol. 68, Aug., pp. 597–607). A description is given of the discovery of a form of graphitization in steam pipes not connected with the heat-affected zone adjacent to a weld. Evidence is produced to show how the precipitation in the case of slip-plane graphitization is nucleated by stress, and it is postulated that tessellated stresses may cause nucleation in the region adjacent to welds.

**Some Aspects in the Development of Alloy Steels.** L. Rotherham. (Metallurgia, 1946, vol. 35, Dec., pp. 75–77). A brief outline indicating some of the directions in which alloy steels have been developed during and since the war, the main purpose of which is to show that our understanding of basic phenomena has advanced. With the continued application of research and control further remarkable advances can be expected.

**The Development of Rolls-Royce Turbo Jets.** (Aeroplane, 1946, vol. 70, Feb. 8, pp. 167–173). Details are given of materials used in the Derwent I engine.

**Tension Testing at Elevated Temperatures.** T. M. Blackmon, P. R. Nourse, and E. H. Plesset. (American Society for Testing Materials Bulletin, 1946, May, No. 140, pp. 32–37). A simple and inexpensive method of heating tension specimens by resistance heating, a method of measuring specimen temperatures, and two types of extensometer and the associated electronic equipment for use with a Baldwin–Southwark recorder, have been developed.

**High Creep Strength Austenitic Gas Turbine Forgings.** D. A. Oliver and G. T. Harris. (Transactions of the Institute of Marine Engineers, 1947, vol. 59, No. 5). The paper describes recent rotor forgings for land and marine gas turbines, and discusses this new field of work in high strength austenitic steels. A full discussion is given of the properties and characteristics of a specific high-strength austenitic steel (G. 18B), and the considerations which govern the choice of gas-turbine rotor and blade materials for long-term service. Certain aspects of creep testing receive detailed attention and the paper concludes with a brief summary of the present state of gas-turbine development from the metallurgical point of view.

**Symposium on Materials for Gas Turbines.** (American Society for Testing Materials, 1946).

**Carbon–Molybdenum Steel for Steam Pipes.** L. Rotherham. (Alloy Metals Review, 1947, vol. 5, Mar., No. 43, pp. 2–5). In relation to carbon steel, the carbon–molybdenum steel has very advantageous creep resistance in the higher-steam temperature ranges, which in combination with its other properties suggest that it can be of definite value for steam piping. On the other hand it has a lower ductility, which makes it essential that care should be exercised in its fabrication and installation. While graphitization has not been proved to occur in pipes of British manufacture, the American experience suggests that care in the production of the material should be extended back to the melting process. The incorporation of 0·5% chromium in the carbon–molybdenum steel is a possible line of future development, which will be better established when further experience has been acquired.

**Dislocation Theory as Applied by N.A.C.A. to the Creep of Metals.** A. S. Norwick and E. S. Machlin. (Journal of Applied Physics, 1947, vol. 18, Jan., pp. 79–87). An equation of steady state creep rate in terms of a specific dislocation mechanism which involves considering the generation of dislocations to be a rate process. Theories of rate processes and of dislocation required for the development of the creep equation are discussed.

**Creep Deflections in Columns.** J. Marin. (Journal of Applied Physics, 1947, vol. 18, Jan., pp. 103–109). This paper offers a rational theory for predicting creep deflections in columns.

**The Development of a High Creep Strength Austenitic Steel for Gas Turbines.** D. A. Oliver and G. T. Harris. (West of Scotland Iron and Steel Institute, 1947, Mar., Preprint). The authors discuss the basic considerations of a steel for gas turbines and the early experiments that were carried out on various austenitic steels. It was found that creep strength increased with increasing temperature of solution heat-treatment and in some cases showed a sudden increase in the region of 1260° C. The effect of the addition of niobium in eliminating embrittlement was explored and finally an austenitic steel was developed (G. 18B), which contained approximately 13% each of nickel and chromium, with 10% cobalt, together with strong carbide-forming elements namely tungsten, molybdenum and niobium. Data are given regarding the phase constitution, effect of temperature of solution on creep, physical constants and fatigue and other mechanical properties at room and elevated temperatures.

**Japanese Metallurgy, High Temperature Alloys for Gas Turbines, Rocket Nozzles and Lines.** (British Intelligence Objectives Sub-Committee, 1947, Report No. B.I.O.S./J.A.P./P.R./583 : H.M. Stationery Office .)

**Special Steels—Notes on Practice at Krupp A.G., Essen and Deutche Edelstahlwerke, A.G., Krefeld.** (British Intelligence Objectives Sub-Committee, 1947, Final Report No. 789 : H.M. Stationery Office).

# METALLURGICAL RESEARCH IN GERMANY SINCE THE WAR*

*By Professor M. Hansen*†

DURING the war intensive metallurgical research was carried out in Germany, but since 1945 it has almost ceased owing to material destruction and damage, the loss of equipment, and the dismissal, in connection with the denazification programme, of the heads of departments and other investigators.

At present a few institutes only, which suffered little or no damage, are able to work normally. These include the Institut für Allgemeine Metallkunde at Göttingen University (Professor G. Masing), the Institut für Metallkunde (Professor G. Wassermann), Metallhüttenkunde (Professor F. Johannsen, and Eisenhüttenkunde der Bergakademie, Clausthal, and the Forschungsinstitut für Edelmetalle at Schwäbisch-Gmünd (Professor E. Raub).

The laboratories of the Institut für Metallkunde (Professor W. Köster) and the Institut für Metallphysik (Professor R. Glocker) of the Kaiser-Wilhelm-Institut für Metallforschung were evacuated to various places south of Stuttgart, which were later included in the French Zone of Occupation. The whole of the equipment, and the library, were confiscated for the equipment of an " Institut de Récherches Métallurgiques " at Tettnang (near Lake Constance), but the material was later sent to the vicinity of Paris and Toulouse. The buildings at Stuttgart, which were severely damaged, have now been largely repaired. The damage and loss suffered by the Institut für Physikalische Chemie der Metalle (Professor G. Grube), situated in the American Zone, were comparatively slight, and it has been possible to carry out some research work there. This summer the institute will begin with work requiring simple apparatus only, devoted mainly to the training of students.

The Kaiser-Wilhelm-Institut für Eisenforschung of Düsseldorf was housed in the buildings of the Clausthal Bergakademie during the last years of the war. Nearly all the equipment was preserved and was recently returned to the partially repaired building at Düsseldorf. Since Professor Körber's death in 1944 Professor F. Wever has been acting as head of the institute, and this appointment has recently been confirmed.

Aachen technical college has suffered greater damage than any other laboratories and the buildings of the Institut für Metallhüttenkunde, Eisenhüttenkunde and Giessereikunde (Professors P. Röntgen, W. Eilender, and E. Piwowarsky respectively) were almost completely demolished, so that research work can only be restarted slowly. The Materialprüfungsanstalt of the Darmstadt technical college (Professor A. Thum) has suffered in the same way.

At the Institut für Werkstoffkunde at the technical colleges of Hanover, Brunswick, and Karlsruhe some limited amount of work is being carried out, mainly for teaching. The Institut für Metallkunde of the Munich technical college has not yet restarted its activities.

The destruction of buildings and the dismantling of apparatus at the institutes of the technical college and the Materialprüfungsamt of Berlin have caused losses which cannot be replaced for many years. The work of the institutes is restricted to the teaching of students, which must be done with very primitive apparatus. The Institut für Werkstoffkunde der Deutchen Versuchsanstalt für Luftfahrt has been dissolved.

The publication of scientific journals had to be suspended to a large extent even before the end of the war. In August, 1946, the first issue of the new periodical "*Metallforschung*" succeeded "*Zeitschrift für Metallkunde*," and in January, 1947 the first post-war issue of "*Stahl und Eisen*" was published. The new periodical "*Archiv für Metallkunde*" has been published in Berlin for some little time. Most of the papers now being published describe research work carried out during the war. Numerous metallurgists at the universities, and in industry, contribute to the FIAT review "*Metallkunde*" with sections on general metallurgy, non-ferrous metals and iron and steel, the editors being Professors M. Hansen (Göttingen) and W. Eilender (Aachen).

The activities of the scientific societies ceased completely with the end of the war. The " Verein Deutscher Eisenhüttenleute " started to function again after a comparatively short interruption, and the " Deutsche Gesellschaft für Metallkunde," as well as the " Gesellschaft Deutscher Metallhütten-und Bergleute," will shortly resume their activities.

A severe limitation in German metallurgical research, in the future, is unavoidable. Whereas formerly the costs were largely borne by industry, research in future will probably have to be financed by the State. The institutes will have to be engaged mainly on problems of fundamental research and the training of the young generation. All research work is supervised by regulation No. 25 of the Control Council, but metallurgical investigations are not appreciably restricted by this order.

* Received March 31st, 1947

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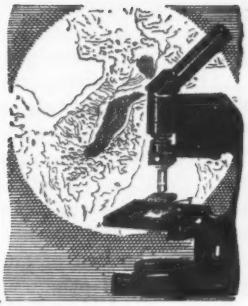

BRITISH IRON AND STEEL RESEARCH ASSOCIATION

# Experiments on Gas Flow in Producer Fuel Beds*

*By M. L. Hughes, M.Sc., F.R.I.C., F.I.M.*†

SYNOPSIS

*The slice model of a static producer previously used in work on fuel distribution in fuel beds has now been used to demonstrate the flow of gas through 'fuel' beds produced in various ways.*

*The path of the gas is shown to depend mainly on size segregation and the relative porosity of ash bed and fuel bed. Experiments have been carried out to show the effect of bell diameter, the use of deflecting devices, size ratio of charge, gas velocity, ash-bed structure, the presence of wall clinker, and layer charging of two fuels. A multicolour technique combined with colour photography has been tried for the latter.*

## *Introductory Remarks*

EXPERIMENTS with a slice model of a static producer[1] have shown that the contour of the fuel bed depends mainly upon the ratio of the diameter of the producer body to that of the bell used for charging. For example, when this ratio is varied from 5·14 to 3·27, the cross-section of the bed remains of the M form, but the peaks move appreciably towards the producer wall. At the same time the valley at the wall diminishes and that at the centre increases. These changes are of considerable importance when the charge consists of material of wide size ratio, because the larger material segregates into these valleys; any change in the positions and relative sizes of the valleys thus alters the size distribution of the charge and hence the permeability of the bed at any given point.

The actual size distribution with a given charging system and size ratio of the charge may be determined with a slice model, and the relative permeability of the several zones of the bed may then be inferred.

It would be more satisfactory, of course, to calculate the relative resistances of the zones, from the known size ratios, but this is not an easy matter. When a cold gas passes through a uniform bed of solid particles of relatively simple geometrical shape, as in many cases in industrial chemical processes, the problem lends itself to mathematical treatment. If the solid is not of simple form, *e.g.*, having a marked cleavage, a 'shape factor' may be introduced, and other corrections are similarly employed. When the solid material is not only irregular in size and shape but is also of wide size ratio, so that packing occurs, the matter becomes increasingly complex. An empirical approach is then called for.

Considerable experimental research on this problem has been carried out. The first extensive work was that of Furnas,[2] who studied the conditions existing in the blast-furnace, with special reference to the conditions obtaining in American furnaces. He deduced a number of relationships between the pressure drop and the other variables of the process. A considerable amount of work has since been carried out on the general problem of gas flow through 'beds of broken solids,' and a useful summary of certain

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aspects of the problem has recently appeared.[3]

The gas producer aspect of this problem has also been examined experimentally both with full-size producers and with models.[4,5] Various methods have been employed to demonstrate the path of a gas (or liquid) through a bed of solid material, colour effects being generally relied upon in order to follow the path of the gas or liquid through the bed of particles. In the work done by Rosin and others,[4] dye was used to colour a stream of water. Bennett and Brown [5] added iodine vapour to the gas stream and treated the charge with starch. They also used chlorine in the gas, and impregnated the charge with potassium iodide. The path of the gas stream is then shown by the liberation of iodine in the charge. This technique was also used to study the aerodynamical conditions in gas producers, chain-grate stokers, and the blast-furnace. The chlorine–iodide method has also been used by Saunders [6] to demonstrate the path of the gases in a model blast-furnace and, later, in similar work on the gas producer.

The purpose of the experiments to be described is to correlate the distribution results already obtained with the slice model of a static producer, and the permeability variations of similar beds produced in the same model. For this purpose a simple and cheap modification of the ' colour ' technique has been utilized, which yields clear and distinct photographs.

### *Experimental Technique*

Marble is used as the charge, chiefly in the 10–20 and 40–60 mesh sizes as used in the distribution experiments. It is treated with lead acetate solution, and dried. A suitable mixed charge of this material is then introduced into the slice model under the chosen charging conditions. The slits in the back of the model, which were made for previous experiments, were sealed off, and the model made generally gas tight. A mixture of air and sulphuretted hydrogen in known proportions is prepared and passed through the charge at a known speed. It enters by a tube placed centrally at the bottom of the model ; in most experiments the tube orifice is covered by a ' hood ' representing a slice through the blast-hood of a producer.

The path of the gas through the charge is indicated by a black stain, and when this has developed to some extent the flow of gas is stopped and a photograph taken. This process is repeated from two to five times, until the gas stream is seen to be issuing strongly at some part of the charge surface. The number of photographs taken depends on the behaviour of the black wave front. It is unfortunate that no equipment was available for taking a series of photographs at fixed time intervals which would give an idea of the rate at which the wave front changes from one form to another.

The use of $H_2S$ lends itself to the production of various colours in different zones of the charge, by impregnating the marble with salts of cadmium, antimony, and lead. For instance, it greatly improves the differentiation between the layers of a ' stratified ' bed, and with suitable lighting conditions colour photographs may be taken. The Dufay colour process has been used in some preliminary experiments in this direction.

### *Gas Flow in an Ideal Uniform Bed*

As a preliminary experiment, in which the result was more or less known beforehand, the gas was passed through a level bed of uniformly sized particles of 20–30 mesh. The gas entered *via* a $\frac{1}{4}$-in.-bore tube, the orifice being flush with the base of the model and covered with a piece of 100-mesh gauze.

Since the bed should be uniformly permeable, the gas should travel equally in all directions and a black semi-circle should appear.

The development of a neat semi-circle is shown in the three photographs on the left of Fig. 1, No. 84. Owing to the presence of the glass front of the model there is danger of preferential flow up the front of the charge, giving a misleading result. This actually occurs to only a very small extent. It may be assessed, roughly, from the fact that the photograph of No. (48c) was taken when the centre of the upper surface of the charge was blackened. The amount by which the front semi-circle had over-shot the upper surface is seen to be relatively small. In the course of later work it was found that ' wall effect ' is surprisingly small when the charge is homogeneous.

The photographs of experiment No. 85, Fig. 1, show the result of using a small hood over the inlet tube. It represents a cross-section through a conical hood 1 ft. in diameter, and here there are two horizontal slits $\frac{1}{8}$ in. wide by which the gas

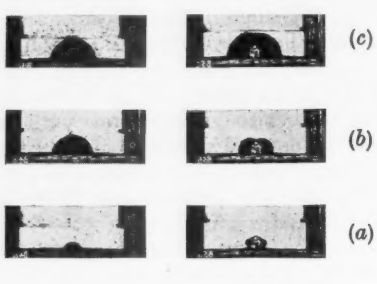


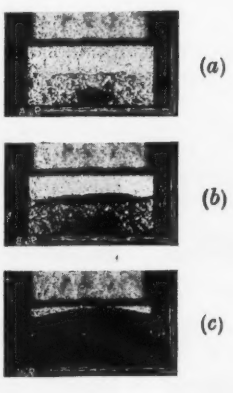

FIG. 1—Flow of gas through a uniformly permeable bed issuing (84) from a $\frac{1}{4}$-in. jet, and (85) *via* a small conical hood

enters, at a height of $\frac{1}{2}$ in., and $\frac{3}{4}$ in. apart. It is seen that there are initially two small semi-circles, somewhat masked by creep along the hood, and these later unite to form a flatter and broader zone than that of No. 84(*c*), Fig. 1.

The hood used in most of the experiments is wider, approximately 2 in., and its upper surface is convex. It represents a cross-section of a mushroom-shaped blast-hood. As would be expected, it produces in a flat bed of 20–30-mesh marble a wave front still broader and flatter than that of No. 85(*c*).

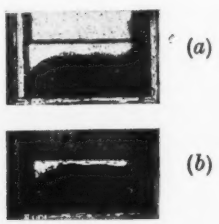
### *Use of a Porous 'Ash-Bed' Layer*

Before commencing the gas-flow examination of the more important distribution results which have been obtained,[1] the following modification was adopted. The charge to be examined was supported by a lower layer of coarser impregnated marble which was first charged to a depth about $\frac{3}{4}$ in. above the hood. It had been found that under these conditions the black wave front could spread outwards almost to the full width of the bed by the time it reached the charge. Then, with a uniform charge the wave front becomes almost a horizontal line ascending the charge. Figure 2 illustrates this point and shows the shape and size of the mushroom hood. The series begins at the top. Note that the marked horizontal spread does not induce wall effect to any marked extent.



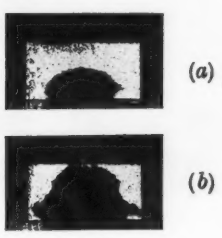

96

FIG. 2—Horizontal spread of gas through porous ash bed followed by uniform flow through homogeneous charge. Ash bed, $\frac{1}{4}$–$\frac{3}{16}$-in. sieves; charge, 10–20 mesh




100

FIG. 3—Disturbance of smooth flow through homogeneous bed, due to clinker at the wall




99

FIG. 4—Gas flow when the ash bed is *less* porous than the charge

It is interesting to note the way in which this smooth flow through a homogeneous bed is disturbed by the presence of a 'clinker' at the wall; probably the chief trouble in gas production. In Fig. 3, No. 100(*a*), the black spot on the right is a $\frac{1}{2}$-in. piece of clinker equivalent to a 6-in. actual clinker. This clinker causes marked wall flow which is seen in No. 100(*b*) to assume serious dimensions. The model experiment thus shows very clearly the marked channelling and wall flow which is known to occur under these conditions.

### *Effect of a Less Porous Ash Bed*

It should be noted that the above effect is not attained if the charge is more porous than the ash bed. Figure 4 shows the result when the charge is 10–20-mesh, as in Fig. 2, but the ash bed is a mixture of $\frac{3}{16}$–$\frac{1}{8}$-in. and 30–40-mesh material. Vertical travel through the charge is obviously easier than horizontal motion through the ash bed, giving the result shown. The irregular form in the ash bed is probably due to segregation effects during charging, the two components being appreciably different in size.

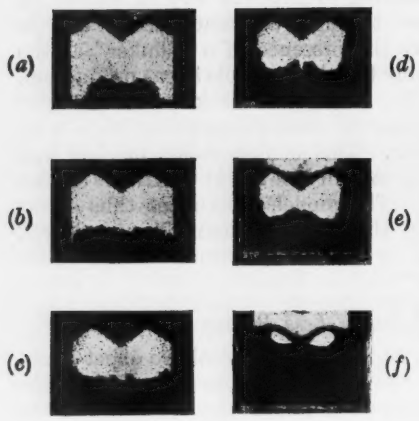
These conditions could arise in industrial practice; the porous uniform fire bed would correspond to a bed of closely graded nuts of non-caking coal with a high-fusion-point ash, working at a fairly low temperature as such coals usually do. Under these conditions very little clinkering or even fritting of the ash would occur and the 'sandy' ash bed produced is quite likely to be less porous than the fuel bed above it. The gas-flow experiments suggest that wall effect is much less likely to develop under such conditions.

### *Influence of Fuel Segregation on Development of Wall Effect*

Figures 2 and 4 show that little wall effect develops in a bed of fairly uniform particles even when the blast has easy access to the walls.

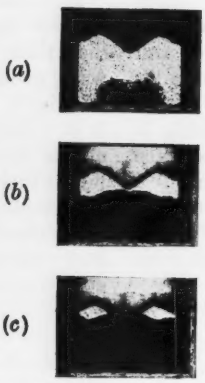
In Fig. 5 we have the contour produced by a $1\frac{3}{4}$-in.-dia. bell in a $7\frac{1}{2}$-in.-dia. body, *i.e.*, a body/bell ratio of 4·03, which is known to result in considerable segregation of the coarser component of a mixed charge towards the walls and the centre. The charge is made up of equal amounts of $\frac{1}{8}$-in.–10-mesh and 30–40-mesh material. The porous ash bed is made up of $\frac{1}{4}$–$\frac{3}{16}$-in. material. The segregation is visible in the earlier photographs taken in this experiment, and the way in which the gas flow follows these porous zones is clearly seen at the third and fourth stages.

It is easy to show that the contour itself, as distinct from the segregation resulting from it, is of considerably less importance. In Fig. 6, the charge is 10–20-mesh only, *i.e.*, an intermediate size, all other factors being unchanged. It is



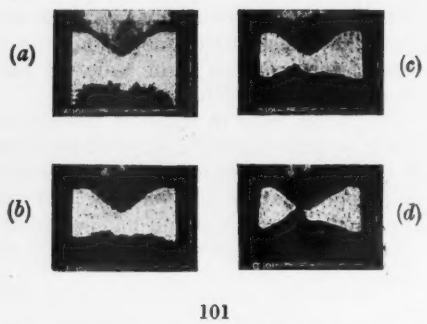

97

FIG. 5—Preferential flow along zones of segregated coarse material. Charge, equal amounts of ¼-in.–10 mesh and 30–40 mesh




98

FIG. 6—Relative absence of wall effect in a charge with the same charge contour and conditions as Fig. 5, but of one component, 10–20 mesh




101

FIG. 7—Conditions as in Fig. 5, but bell lowered to the ' open ' position

seen that the wave front actually reaches the central valley with only a slight tendency to wall effect. This should be contrasted with Fig. 5, stages (*b*)–(*d*), which shows the development of marked preferential wall flow long before the central valley is reached.

*Change due to ' Open-Bell ' Conditions*

Distribution experiments[1] have shown the marked change in contour and in size distribution when a bell of a given size is used as a distributor instead of as a charging method. The probable influence upon wall effect could be foreseen.

Figure 7, No. 101, shows the result of using the same 1¾-in. bell as in Nos. 97 and 98, Figs. 5 and 6, but lowered to the open position. There is, as expected, a marked central preference with only a small wall effect on the left. This is in marked contrast to No. 97, Fig. 5. The actual result is unfortunately not symmetrical, probably due to an irregularity in the rolling towards the centre which is sometimes observed.

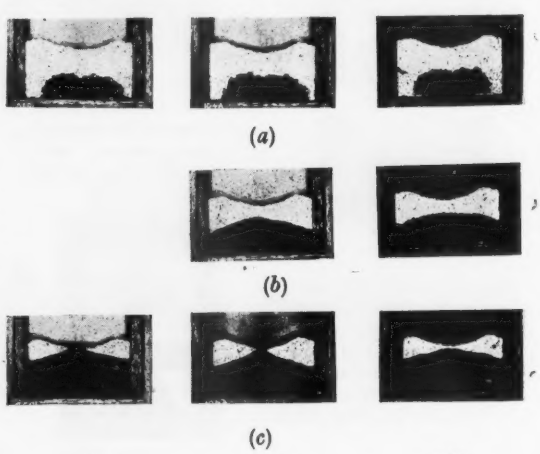
*Use of Auxiliary Deflecting Devices*

Although the last result eliminates wall effect, the central weakness is too marked. This may be corrected by the use of suitable deflectors, in conjunction with ' open-bell ' charging, such that a suitable proportion of the charge is deflected inwards towards the centre. Such an arrangement has been shown to produce a much improved size distribution.[1] This should lead to greater uniformity of gas flow, which is confirmed by experiment.

In Fig. 8, the charge, and all other factors except gas velocity, are as in the open-bell experiment shown in Fig. 7 but using the full-width deflectors described in the author's paper on fuel distribution.[1] Three results are shown representing three rates of gas flow : medium, No. 103 ; fast, No. 104 ; and slow, No. 113. The wave fronts are seen to differ by only a relatively small amount, an increase in the rate apparently favouring central gas flow. The results confirm the conclusions which would be drawn from the corresponding size-distribution experiment. The question of gas velocity will be discussed later.

*Variation of Bell Size, Contour Produced, and Gas Flow Pattern*

In the introductory statement, reference was made to the effect on fuel-bed contour of variation in body/bell ratio (*B*/*b*). The effect on the peaks and valleys is seen in Fig. 9, reproduced from the




103 104 113

FIG. 8—Increased uniformity of gas flow by using a deflector mechanism when charging. Three rates of gas flow, (104) fast, (103) medium, and (113) slow

previous work on distribution.[1] The effect upon the relative amounts of segregation at the walls and centre is evident from the diagram, and it could be deduced that the contour $B/b = 5 \cdot 14$ would cause so much wall segregation that marked wall effect would arise ; on the other hand curve $B/b = 3 \cdot 27$ is appreciably higher at the walls than at the centre, and there is also less room for wall segregation. We could only say from this that wall effect is much less likely in the latter case.

The gas-flow examination of this question shows that a change from a $1\frac{3}{4}$-in. bell to a $2\frac{1}{4}$-in. bell, using a $7\frac{1}{2}$-in. body width, is sufficient to reduce considerably a marked wall preference and replace it by a small central preference.

A further increase to a $2\frac{3}{4}$-in. bell almost completely eliminates the wall effect and slightly increases the central preference. The results are shown in Fig. 10, and the comparison is best seen from photograph (*b*) in each case. The charge was in each case $\frac{1}{8}$-in.–10-mesh plus 30–40-mesh material in equal proportions, and the gas velocity was maintained constant by means of a flow meter.

These results are modified by a change in the components of the charge. If the larger component is increased in size then the effect of its segregation is greater. For example, there is very little wall effect in experiment No. 108, Fig. 10. When this is repeated using $\frac{3}{16}$–$\frac{1}{8}$-in. instead of $\frac{1}{8}$-in.–10-mesh material, the wall effect is partially restored. This is seen in Fig. 11, No. 109, the result on the right being No. 108 (Fig. 10, left), reproduced here for comparison. The reappearance of wall flow in No. 109, when the larger component is increased in size, is accompanied by a change in the central gas flow which is seen to be diminished. This interdependence of various zones in the bed is as would be anticipated and has been revealed by this technique on several occasions.

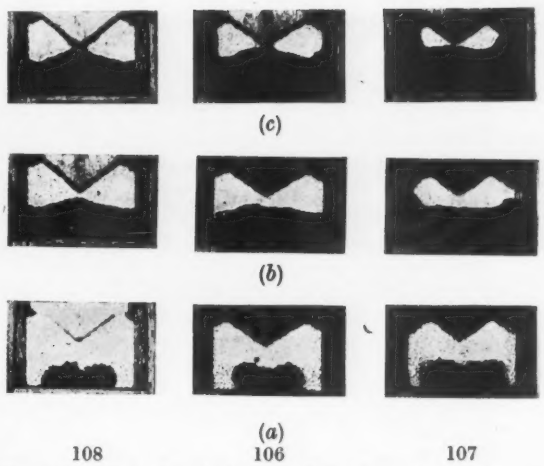



FIG. 10—Effect of variation of bell size on contour, segregation, and gas flow ; bell sizes (108) $2\frac{3}{4}$ in., (106) $2\frac{1}{4}$ in., and (107) $1\frac{3}{4}$ in.

*Local Variation in Size within the Ash Bed*

It has been shown that the relative permeability of ash bed and fuel bed has a marked effect on gas flow, the fuel bed being uniform in each case (Figs. 2 and 4).

In industrial practice the structure of the ash bed may vary appreciably from point to point. Static producers frequently work hot at the wall and centre with a comparatively cool annular zone between. This condition may be reflected in the ash bed. The ash at the centre and wall may be porous due to fritting and clinkering but relatively impermeable in between due to ' sandy ' ash derived from the cool annular zone.

If that condition exists then a barrier may be set up around the hood which might well reduce

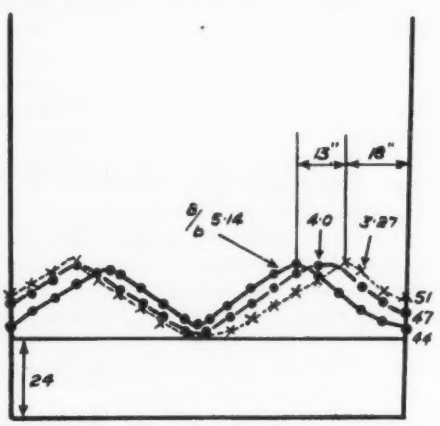



FIG. 9—Variation of fuel-bed contour with changing body/bell ratio ; closed bell

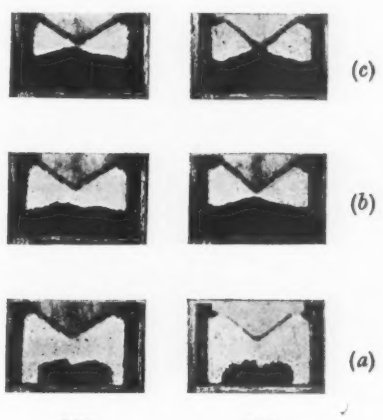
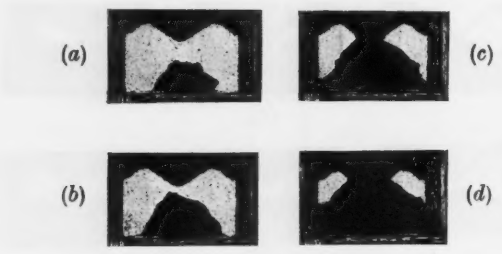



FIG. 11—Size of large component as a factor influencing segregation results



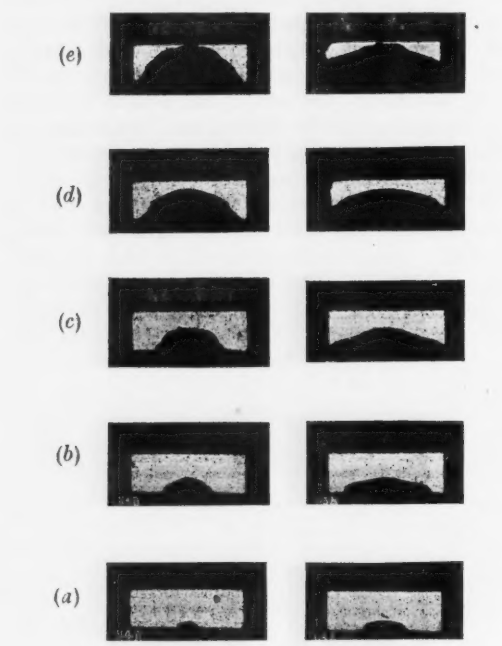

111

FIG. 12—Local zones of lower porosity in ash bed, causing change of gas flow

the tendency to wall effect. An attempt has been made to imitate such conditions, and the result is seen in Fig. 12.

The charging conditions here are those leading to extreme wall effect, *viz.*, those of No. 97 (*d–f*), Fig. 5 and No. 107, Fig. 10, but the ash bed includes a pocket of less permeable material midway between the hood and the walls. A third of the ash bed is still $\frac{1}{4}$–$\frac{3}{16}$-in. mesh, but the other two thirds is a mixture of $\frac{1}{8}$-in.–10-mesh and 40–60-mesh material, which mixture is concentrated into the two zones referred to.

The gas-flow result shows the expected obstructive effect, and the final result is quite different from that with a uniformly porous ash bed. This




114 115

FIG. 13—Gas flow in stratified beds : charge ; fine 40–60 mesh ; coarse, 10–20 mesh. Velocity faster in 115

is an instance of the necessity for considering ash bed and fuel bed as a unit in any comprehensive study of the aerodynamics of producer beds ; it is also an example of the way in which the initial permeability variations in a fuel bed may prove to be self-aggravating or the reverse.

*Gas Flow in Stratified Beds*

The fuel bed is not normally in a stratified condition except, temporarily, when a change to a different type of fuel is necessary. The effect of this upon the working of a producer is said to be sometimes quite marked, but to depend on the order of using the coals. This was at first considered to be a matter of relative permeability similar to that of ash bed and fuel bed previously discussed. A change from through to sized coal would correspond to the condition of Fig. 4 leading to reduced wall flow.

Stratified fuel beds would also arise if the problem of excessive size ratio were approached along the following lines. Although it is not economically possible to grade South Wales gas coal in the ordinary sense, it might be possible to divide it into two portions, above and below say, $\frac{3}{16}$ or $\frac{1}{4}$ in., and gasify these separately. The coarser part would be considerably easier to gasify due to greatly reduced packing, etc., while the small material might not be as difficult as it seems. In fact, if the really dusty component were removed it might prove quite tractable in the producer. A relatively uniformly-sized bed of this material is more porous than one of excessively-wide size ratio containing all of the small-size material. The back-pressure would be high but the increased uniformity would be a big advantage.

There is also the possibility of charging the two sizes alternately into *the same producer*. It has been shown [3] that the pressure drop through a bed of two components arranged in layers is not appreciably different from a bed of the mixed components, provided the size ratio is low.

It was thought that gas-flow experiments on such stratified beds might yield interesting results. Each layer would present a reasonably uniform path to the gas but the permeability would fluctuate from layer to layer. The results obtained when using alternate layers of 10–20 and 40–60-mesh material and introducing the gas without a hood, are shown in Fig. 13. The wave front spreads horizontally when it meets a 40–60-mesh layer but shows a central preference on entering a 10–20-mesh layer. This is in agreement with previous results with ash beds and fuel beds. The series on the right (Fig. 13, No. 115) shows the effect of faster blowing.

The influence of gas velocity appears to be much more pronounced in beds of this type than in normal beds. An increase in velocity increases

the difference in spreading behaviour, presumably due to a greater difference in permeability as the velocity increases. In Fig. 14 the velocity is increased further and the effect is more marked.

*Colour Photography*

The final photographs in the stratified groups do not show the layer structure of the beds, and for this reason the technique was varied to produce different colours in the layers, as described earlier. This worked quite satisfactorily, but the idea was not pursued. Figure 15 is a panchromatic photograph of a multi-coloured bed, and the layers are seen to be quite distinct.

*Influence of Gas Velocity in Model Experiments*

The effect of increasing the gas velocity on the results obtained with stratified beds is seen to be quite marked, whereas in previous experiments very little effect had been seen.

The earlier gas-flow experiments had been regarded as exploratory, and the gas flow had been slow for convenience in observing the general behaviour and in taking photographs of any significant changes. The velocity was gradually speeded up, but no control by means of a flow meter was employed until the experiments of Fig. 8 were carried out. The effect of variation in gas velocity was now tried, and it is seen that the result is an increase in the central preference. This is not very marked but may be seen from the gradual increase in steepness of the central peak. The fastest and slowest are adjacent in Fig. 8, being No. 104 and No. 113, respectively. All these velocities are very low, being 0·14, 0·24, and 0·34 litres/min. A certain minimum velocity is clearly necessary in these experiments in order to make the effect of diffusion a negligible factor. The maximum velocity required is that which would yield a Reynolds number (*Re*) comparable with that of actual producer operation. This is impossible to achieve in these model experiments because the velocity required would be too high. The reduction in the linear dimensions of the model to $\frac{1}{12}$th of actual producer sizes would require an increase of the gas velocity in the model to twelve times that of actual practice, in order to maintain the same Reynolds number and so achieve dynamic similarity. This assumes that the differences in density and viscosity of the gas mixture are not significant.

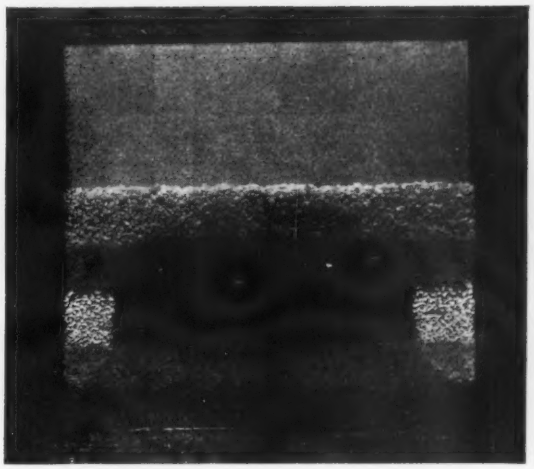


FIG. 15—Coloured layers in stratified bed

Evidently the highest convenient velocity is to be aimed at, but it seems that a comparison between two experiments gives the same general result over quite a range of velocity. For example, Fig. 5, showing marked wall preference, was carried out before gas velocities were calibrated, but the velocity is known to be low. This experiment (No. 97) was later repeated at a higher velocity, though still only 0·27 litres/min. The result, seen in No. 107, Fig. 10, is to show the same marked wall effect. Much later in this work a considerably higher velocity was used to check the conclusions already reached, that :

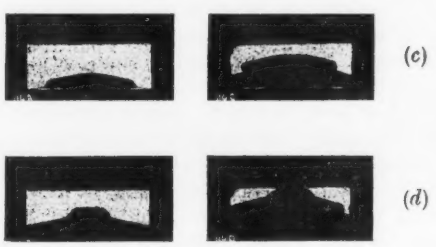
(i) The bell, $1\frac{3}{4}$ in. width and charge employed in experiments Nos. 97 and 107 (Fig. 5 and Fig. 10), produce marked wall effect.

(ii) Changing the bell width to $2\frac{1}{4}$ in. is sufficient to cancel most of this wall effect and introduce some central preference. (No. 106, Fig. 10.)

(iii) Segregation, and not contour, is the cause of wall effect (Fig. 6).

These three experiments were repeated at approximately ten times the velocity originally used (2·56 litres/min.), and the results are shown together in Fig. 16.

The resemblance between, for instance, the middle photograph of the centre group, *i.e.*, No. 129(*b*), and the corresponding middle photograph of experiment 107, Fig. 10(*b*), is striking. The tenfold increase in gas velocity has apparently made no difference. Experiment 130, Fig. 16, also yields a result very similar to that of experiment 106, Fig. 10. On the other hand in experiment 131, Fig. 16, there is less wall tendency than in the




116

FIG. 14—As in Fig. 13, but with increased gas velocity

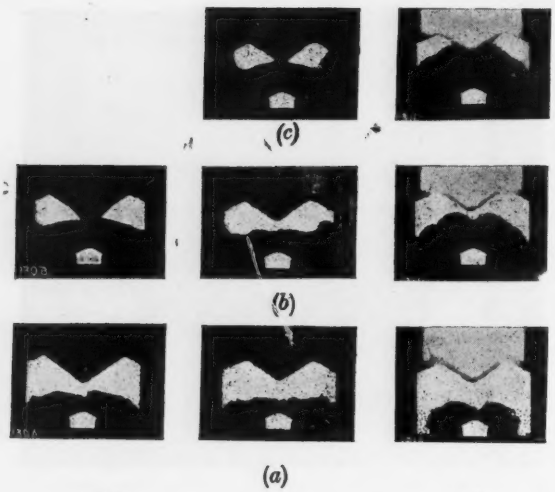



FIG. 16—Repeat experiments using a gas velocity ten times greater; compare 130 with 106 (Fig. 10), 129 with 107 (Fig. 10), and 131 with 98 (Fig. 6)

corresponding slow experiment 98, Fig. 6. The conclusion drawn from experiment 98 (Fig. 6) compared with experiment 107, Fig. 10, that the contour of the latter is not, *per se*, a source of wall effect, is amply confirmed in the experiments at high speed, *viz.*, Nos. 131 and 129, Fig. 16.

The net result of a substantial increase in velocity is thus to show a comparatively small increase in central flow, the original conclusions being corroborated. There has not been any sudden transition in the nature of the gas flow as is seen at the critical Reynolds number, and it may be that the roughness of the material and the nature of the experiments in general, lead to the development of turbulent flow at relatively low values of *Re*. No further work has been done in this direction or with regard to the unexpected result with stratified beds, owing to the pressure of other work.

### *Other Factors Affecting Model Experiments*

Mention has already been made of the fact that a high velocity minimizes the effect of diffusion and makes better aerodynamic comparison with actual producer practice. In addition, it reduces the relative effect of lag in the observed wave front, due to absorption of $H_2S$ by the charge, a factor which enters into all such methods of observing gas flow. For the same reason it is necessary to keep the content of lead or other elements to the minimum consistent with clearly defined photographs.

In this connection it may be mentioned that the charge should not be used immediately after drying by heating. A trace of moisture is needed for the colour to develop quickly, although this does not arise with lead so much as with antimony and cadmium.

It was thought at first that the smooth planed sides of the model would increase the tendency to produce wall effect compared with the relatively rough wall of a brick-lined producer. It is not uncommon to find, in rotating producers or static models fitted with levellers, horizontal grooves around the body, which may be $\frac{1}{2}$ in. or more in depth. However, it has been shown that wall effect is less than was expected.

### *Gas-Flow Experiments in Relation to Producer Operation*

It is realized of course that gas flow in a cold bed is very different from that existing during gasification. In addition to the effect of high temperature upon the viscosity of the gas, the existence of temperature gradients is virtually equivalent to size segregation in its effect. The physical condition of the bed changes first by caking, with some coals, and then as a result of combustion which proceeds at different rates in different zones. As has been shown, and is well known, clinkering is a powerful influence, while variations in combustion rates may be followed by variations in ash-bed permeability which may in turn either aggravate or cancel the first cause. This question was referred to in the introductory remarks to the author's paper[1] "The Distribution of Fuel in Gas Producers," and it need only be pointed out here that the uniformity of charging, and thus of permeability, when the producer is *first put into operation*, is alone worthy of the closest study.

It is known that a gas producer which begins badly is likely to remain in poor shape. Even when a producer begins well it is likely to deteriorate later, but this may be due to the initial uniformity of the bed being lost owing to a poor charging system causing excessive segregation. The contrast between these two conditions has been very well shown by Noyes,[7] who varied the initial condition of the bed and obtain strikingly different performances. His 'good' bed gradually deteriorated, but he gave no information on fuel distribution such as flapper angles in Morgan producers. It is thus possible that his initial good period would have been considerably prolonged if care had been taken to ensure adequate fuel at the wall and a minimum of wall effect.

Some of the effects shown in the model experiments would be self-correcting in practice. A small central preference would lead to caking there which would deflect the flow elsewhere. The rise in temperature at the centre would also serve to spread the gasification. The position is different when there is a wall weakness. The

heat developed would promote caking in the upper bed in a direction away from the wall but would not affect the zone at the wall face. The rise in temperature would, however, tend to counteract the wall effect by its influence on viscosity but, in general, this would be more likely to persist, leading to more rapid combustion at the wall and an aggravation of the initial weakness. The possibility of clinker at the wall makes this condition of wall weakness a great danger to successful gasification. Its avoidance when using through coal is clearly a matter of controlled distribution to produce a wall zone of reduced permeability. This is not, of course, a new conclusion, but it has been arrived at by a different method. Producers have been modified so as to throw fines to the wall [8] and in one case at least, a water-gas-producer grate was altered to prevent the blast from reaching the walls too easily.[9] In such cases much improved performance has resulted, though with loss of gasification rate and possibly the production of some bad gas due to the very cold wall zone.

The logical method of producing a desired gas flow seems to be that of controlled fuel distribution by any method suited to the producer concerned and the fuel used in it.

The model experiments described here and in the author's previous paper [1] suggest that this technique is capable of providing some of this badly needed information with a minimum of delay and expense.

### *Conclusions*

1. The flow of gas from a small orifice, through a uniform bed of granular solids, at a low speed, yields a hemispherical wave front as would be expected.

2. At the low velocities employed the form and size of the blast-hood influenced the shape of the wave front.

3. In a non-uniform bed of mixed materials the contour is of much less significance than the size segregation caused by it. The greater the size ratio the greater is this effect.

4. Gas velocity may be varied considerably, with little effect on the wave front produced.

5. A comparatively small change in bell size in static producers may cause a marked change in gas flow without altering the *form* of the fuel-bed contour.

6. The relative permeability of ash bed and fuel bed has a marked effect. A porous ash bed increases lateral spread of the wave front, but a porous fuel bed on a less porous ash bed induces a central preference.

7. The injurious effect of a clinker at the wall is clearly shown by this technique.

8. The existence of hot and cold zones in the fire may lead to coarse and fine zones in the ash bed, and this may modify gas flow appreciably.

9. The improved distribution results produced by internal deflectors in static producers is now seen to be accompanied by more uniform gas flow.

10. 'Wall effect' is slight when the charge is uniform in size, irrespective of the fuel-bed contour. Note that when operating such a uniform bed, the cooling effect at the walls due to radiation losses would induce a 'wall effect' quite unconnected with porosity, segregation, etc. (*see* Fehling [10]). Segregation of coarse material to the wall induces wall effect, and the effect is greater when the size disparity is greater.

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# The Effect of Speed of Rolling in the Cold-Rolling Process*

*By H. Ford, Wh.Sch., B.Sc.(Eng.), Ph.D., M.I.M.E.*†

SYNOPSIS

*Tests have been made on 0·2%-C steel, 0·07%-C steel and high conductivity copper rolled at various speeds up to 300 ft./min. in successive passes and with a constant percentage reduction in each pass.*

*The results confirm previous researches in that, with pass reductions up to 60%, the rolling pressure required for a first pass is substantially independent of the speed of rolling. In subsequent passes, however, after work hardening and when the strip is thin, roll pressure is markedly dependent on speed, and is highest at the lower speeds. The corresponding energy consumption also depends on speed, but to a smaller extent and in a more complex manner. The paper thus establishes on a quantitative basis the well-known facts that roll force and, to a lesser extent, roll torque, are dependent on speed when rolling fairly thin strip.*

*Some possible causes of these effects,* viz., *dependence of yield stress on rate of deformation, effect of temperature rise resulting from the work of deformation, roll flattening, and lubrication are discussed, and all are regarded as not providing complete explanations.*

*It is concluded that these phenomena, which undoubtedly contribute to the occurrence of gauge variations during acceleration and deceleration when rolling thin strip, require further consideration, and it is hoped that the paper will stimulate interest.*

## INTRODUCTION

THE cold rolling of steel and non-ferrous strip and sheet is carried out at widely different speeds. The trend is towards higher speeds, particularly in the steel industry. It is a matter of experience that the gauge of strip changes during acceleration and deceleration in modern high-speed mills in a way which cannot be accounted for entirely by change in strip tension, and it would seem to be an effect only of the changing speed.

In connection with the programme of research into problems of cold rolling undertaken by the British Iron and Steel Research Association, some values of roll separating force and roll torque were obtained at various strip speeds on an experimental 10 × 10-in. two-high mill.[1] The results showed an effect of rolling speed not noticed by previous workers, and it was decided that a fuller investigation of this effect should be made.

## PREVIOUS RESEARCHES

Little published work exists on this subject (though Mohler[2] noted the effect of speed variation on the finished gauge when all mill settings other than speed remained constant), since the yield stress characteristics of metals during cold deformation have usually been found to be unaffected by the rate of deformation[3] over a wide range, and it has therefore been usual to assume that the same would hold true in the rolling process.

Referring to the tensile test experiments, most of the tests have been made with a tensile impact tester. With regard to the yield point in steels, Ginns,[4] Brown and Vincent,[5] and Taylor[6] all found that there was an increase (in some cases up to 100%), but in general the ultimate stress was not increased. In those steels where there is no definite yield point no significant rise in the stress at which yielding occurs has been found by these workers.

Brown and Vincent have shown stress/strain curves, obtained in static tests, for heat-treated low carbon steels (which exhibit a definite yield point), and have compared them with the stress/strain curves for rates of deformation up to 900 sec.$^{-1}$. Examination of these curves will

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show that the change in the stress/strain relation for high-speed deformation, compared with that for the static test, is confined to the first 5–10% of the deformation. Taylor found that for very high speeds of deformation (1500 to 3000 sec.$^{-1}$) there was some considerable increase in the yield stress over the whole range of deformation for mild steel, but that there was no essential increase in stress, due to the rate of straining, for pure annealed copper.

These results would therefore tend to show that except for the first ten per cent deformation in annealed mild steel, the yield stress characteristics of materials are unlikely to be much affected at the rates of deformation met with in cold rolling, any effect tending to increase the yield stress, not to decrease it.

Actual rolling tests so far published support this conclusion where the experiments refer only to *single passes* made on strip initially fairly soft or thick. A previous review[7] of the experimental results for varying speeds of cold rolling showed that only the S.K.F. (Svenska Kullager Fabrik—Swedish Ball-Bearing Company) organisation in Sweden had made more than one pass on a single strip. The S.K.F. experiments were carried out in an 8-in. mill using 0·15% and 1·0%-C steels and brass, at speeds of 49, 87, and 191 ft./min. These workers formed the conclusion that speed has only a small effect on the mean roll pressure : it was less at 49 and at 191 ft./min. than at the intermediate speed of 87 ft./min. They attributed this to more oil being carried along on the surface of the roll at the higher speed, but appeared to be rather doubtful whether much attention should be paid to the results, although they stated in their conclusions that for hard and thin strips there appeared to be some change in the mean roll pressure with change in speed.

Other workers examined the result of making only single pass reductions on fairly thick material

TABLE I—*Results Obtained by Cold Rolling 3 × 0·10-in., 0·2%-C Electric-Furnace Steel on 10 × 10-in. Mill*

*All 30% per pass. Rolls not reset between tests at different speeds. Vacuum A 40 oil*

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Strip No. | Rolling Speed, ft./min. | Reduction in Pass, % | Reduction Overall, % | Mean Thickness before Pass. in. | Mean Thickness after Pass, in. | Mean Width before Pass, in. | Mean Width after Pass, in. | Contact Area, sq. in. | Total Roll Force, tons | Mean Roll Pressure, tons/sq. in. | Rate of Rolling, tons/hr. | Nett Torque per Roll, tons in. | Energy Consumption, h.p.hr./ton | Total Energy, h.p.hr./ton |
| | | (i) *1st Passes* | | | | | | | | | | | | |
| 1 | 40 | 30·0 | 30·0 | 0·1002 | 0·0701 | 2·994 | 3·017 | 1·167 | 56·3 | 48·2 | 0·76 | 9·1 | 12·9 | 12·9 |
| 2 | 40 | 29·8 | 29·8 | 0·1002 | 0·0703 | 2·994 | 3·017 | 1·160 | 57·0 | 49·2 | 0·77 | 8·7 | 12·3 | 12·3 |
| 3 | 96 | 30·4 | 30·4 | 0·1001 | 0·0697 | 2·993 | 3·019 | 1·172 | 57·0 | 48·6 | 1·82 | 9·3 | 13·3 | 13·3 |
| 4 | 96 | 30·2 | 30·2 | 0·1003 | 0·0700 | 2·995 | 3·018 | 1·169 | 57·0 | 48·8 | 1·84 | 9·3 | 13·2 | 13·2 |
| 5 | 231 | 30·6 | 30·6 | 0·1000 | 0·0694 | 2·994 | 3·018 | 1·175 | 58·0 | 49·4 | 4·36 | 9·3 | 13·4 | 13·4 |
| 6 | 226 | 30·4 | 30·4 | 0·0995 | 0·0693 | 2·993 | 3·017 | 1·166 | 56·6 | 48·5 | 4·29 | 9·4 | 13·5 | 13·5 |
| | | (ii) *2nd Passes* | | | | | | | | | | | | |
| 1 | 38 | 30·4 | 51·3 | 0·0701 | 0·0488 | 3·017 | 3·037 | 0·987 | 64·5 | 65·4 | 0·51 | 9·1 | 18·2 | 31·1 |
| 2 | 38 | 30·7 | 51·4 | 0·0703 | 0·0488 | 3·017 | 3·036 | 0·992 | 65·4 | 65·8 | 0·51 | 9·1 | 18·2 | 30·5 |
| 3 | 97 | 30·0 | 51·2 | 0·0697 | 0·0488 | 3·019 | 3·040 | 0·978 | 65·2 | 66·6 | 1·32 | 9·3 | 18·6 | 31·9 |
| 4 | 97 | 30·8 | 51·6 | 0·0700 | 0·0485 | 3·018 | 3·040 | 0·994 | 65·0 | 65·4 | 1·30 | 9·3 | 18·9 | 32·1 |
| 5 | 220 | 30·8 | 52·0 | 0·0694 | 0·0480 | 3·018 | 3·040 | 0·990 | 64·3 | 64·9 | 2·90 | 9·4 | 19·4 | 32·8 |
| 6 | 219 | 32·2 | 52·8 | 0·0693 | 0·0470 | 3·017 | 3·038 | 1·012 | 65·0 | 64·3 | 2·82 | 9·5 | 20·0 | 33·5 |
| | | (iii) *3rd Passes* | | | | | | | | | | | | |
| 1 | 37 | 29·3 | 65·6 | 0·0488 | 0·0345 | 3·037 | 3·056 | 0·817 | 67·8 | 83·0 | 0·35 | 7·4 | 21·0 | 52·1 |
| 2 | 36 | 28·8 | 65·3 | 0·0488 | 0·0347 | 3·036 | 3·058 | 0·811 | 67·8 | 83·6 | 0·35 | 7·3 | 20·6 | 51·1 |
| 3 | 96 | 30·7 | 66·2 | 0·0488 | 0·0338 | 3·040 | 3·058 | 0·836 | 68·5 | 81·9 | 0·90 | 7·6 | 22·0 | 53·9 |
| 4 | 96 | 31·2 | 66·6 | 0·0485 | 0·0334 | 3·040 | 3·058 | 0·839 | 67·8 | 80·8 | 0·89 | 7·3 | 21·4 | 53·5 |
| 5 | 220 | 32·5 | 67·6 | 0·0480 | 0·0324 | 3·040 | 3·058 | 0·854 | 66·2 | 77·5 | 1·98 | 7·9 | 23·8 | 56·6 |
| 6 | 220 | 32·4 | 68·1 | 0·0470 | 0·0318 | 3·038 | 3·058 | 0·842 | 66·1 | 78·5 | 1·94 | 8·1 | 24·9 | 58·4 |
| | | (iv) *4th Passes* | | | | | | | | | | | | |
| 1 | 36 | 30·2 | 75·9 | 0·0345 | 0·0241 | 3·056 | 3·083 | 0·701 | 85·8 | 122·5 | 0·24 | 7·6 | 30·7 | 82·8 |
| 2 | 36 | 33·7 | 77·1 | 0·0347 | 0·0230 | 3·058 | 3·083 | 0·744 | 86·7 | 116·5 | 0·23 | 7·7 | 32·6 | 83·7 |
| 3 | 95 | 37·3 | 78·8 | 0·0338 | 0·0212 | 3·058 | 3·089 | 0·775 | 81·7 | 105·4 | 0·56 | 8·2 | 37·6 | 91·5 |
| 4 | 95 | 37·8 | 79·2 | 0·0334 | 0·0208 | 3·058 | 3·089 | 0·775 | 81·2 | 104·8 | 0·55 | 8·2 | 38·4 | 91·9 |
| 5 | 225 | 43·8 | 81·8 | 0·0324 | 0·0182 | 3·058 | 3·094 | 0·821 | 76·0 | 92·5 | 1·14 | 8·6 | 45·8 | 102·4 |
| 6 | 225 | 43·9 | 82·1 | 0·0318 | 0·0178 | 3·058 | 3·096 | 0·811 | 76·6 | 94·4 | 1·12 | No reading | ... | ... |

and found no influence of speed on roll force and torque.

Thus, tests were carried out by Emicke and Lucas[8] using single passes of 13% reduction on 0·079-in. thick duralumin. They found a rise of about 3% in roll force over a range from 10 to 307 ft./min., but an examination of the intermediate points suggests that this amount may be no greater than the limits of accuracy of the measuring devices.

Siebel and Lueg[9] made tests on a mill with 7·3-in. dia. rolls at speeds of 0·5, 19·1, and 69 ft./min. for various single-pass reductions up to 54%, using a 0·17%-C steel. No differences were found over this speed range.

Only Emicke and Lucas[8] have studied the effect of speed on torque. They found about 4% rise in the torque at speeds of from 10 to 307 ft./min.

## Rolling Tests on 0·2%-C Steel

Previous rolling tests on the Sheffield experimental mill[7] for various reasons had been carried out at 40 ft./min., but during tests on a 0·2%-C electric-furnace steel, speeds from 5 up to 300 ft./min. were used.

The strip was initially 0·1 in. thick × 3 in. wide, and was in the fully-annealed condition. It had the following composition :

| C, % | Mn, % | Si, % | S, % | P, % |
|---|---|---|---|---|
| 0·20 | 0·38 | 0·070 | 0·030 | 0·017 |

The yield point was about 15 tons/sq. in., the ultimate stress 24·0–25·1 tons/sq. in., and the elongation from 32–35%. The steel was specially prepared for these tests and was extremely uniform in properties throughout.

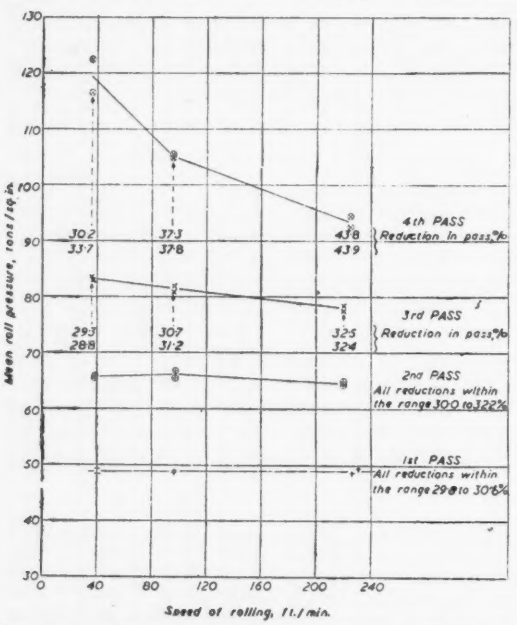


Fig. 1—Variation of mean roll pressure with speed; 0·2%-C electric-furnace steel, coil 65, short lengths of 3 × 0·1-in. strip

It was decided not to limit the tests to single passes, but to continue in successive passes of equal amount until no further reduction was practicable.

In the first series of tests nominal speeds of 40, 100, and 240 ft./min. were selected, and test pieces of the annealed material approximately 3 ft. long were prepared. For any given schedule of reductions, the lengths were tested in pairs. These two pieces, originally adjacent in the coil, received, as near as possible, identical treatment, the object being to obtain duplicate sets of results for each pass. Thus, in all, six strips as near together in the coil as possible were used, two for each speed.

The reduction in all passes was 30% of the strip thickness at the start of each pass. The rolls were adjusted, by means of short trial pieces cut from the same coil of strip, until the desired reduction of 30% in the first pass was obtained when operating at a rolling speed of 40 ft./min. The first pair of strips was then rolled at this speed, the readings of roll force, torque, mill power, and so on, being noted ; the speed of the mill was then increased successively to 100 and 240 ft./min., and the appropriate test lengths were given their first passes, but without altering the roll setting from that used for the test lengths at 40 ft./min.

The same procedure was adopted for the second, third, and fourth passes, each representing a reduction of 30% in the pass ; that is to say, the rolls were adjusted to give the desired reduction at 40 ft./min., and this setting was not altered for the passes at 100 ft./min. and 240 ft./min.

### *Results of the First Speed Tests*

The relevant results are given in Table I and the mean roll pressures are shown in Fig. 1. The mean roll pressure is defined as :

$$p = \frac{\text{Total roll force}}{\text{Area of undeformed arc of contact}} = \frac{P}{b\sqrt{R(h_1 - h_0)}}$$

where $b$ = mean of widths of strip before and after the pass (in.)
$R$ = roll radius (in.)
$h_1$ = strip thickness before pass (in.)
$h_0$ = ,, ,, after ,, (in.)
$P$ = total roll force (tons).

In Table I, values of roll torque and energy consumption are given. The figures in column 13, "Nett Torque per Roll," are the means of the readings of the torque meters fitted to the upper and lower spindles of the mill, allowance being made for the losses in the roll-neck bearings, in the way described in a previous report.[1] The

figures represent, therefore, the torque required per roll for the deformation of the material. The energy consumption figures are obtained from the figures of nett torque per roll as follows :

Let $T$ = nett torque per roll (tons in.)
$a_o$ = cross-sectional area of the strip at exit from the rolls (sq. in.)
$\rho$ = density of strip material (lb./cu. in.)
$v_o$ = surface speed of the strip at exit, assumed equal to the surface speed of the rolls which is $2\pi Rn$ (ft./min.)
$R$ = radius of roll (ft.)
$n$ = revolutions of roll per minute (r.p.m.).

Then the amount of material passing through the rolls

$$= \rho \times 2\pi Rn \times a_o \times 12 \times \frac{60}{2240} \text{ tons/hr.}$$

Rate of consumption of energy in deforming this material

$$= \frac{2\pi nT \times 2}{12} \text{ ft. tons/min.}$$

Therefore power consumed

$$= \frac{2\pi nT \times 2 \times 2240}{33{,}000 \times 12} \text{ h.p.}$$

and the energy consumption, in h.p.hr./ton

$$= \frac{2 \times 2\pi nT \times 2{,}240 \times 2{,}240}{12 \times 33{,}000 \times 2\pi Rn\rho a_o \times 12 \times 60}$$

$$= 0{\cdot}0855 \frac{T}{\rho a_c}$$

This is the energy consumption in the pass. The total energy consumption is the cumulative figure for any strip as the result of several passes upon it. For steel, $\rho$ was taken as 0·28 lb./cu. in. and for copper, 0·343 lb./cu. in.

The figures against the points plotted for the third and fourth passes in Fig. 1 are the actual reductions in the passes.

It was found that for the first pass the pressure was not dependent on the speed, and that the roll setting which gave 30% reduction at 40 ft./min. gave the same reduction at 100 and 240

TABLE II (*a*)—*Results Obtained by Cold Rolling 3 × 0·10-in., 0·2%-C Electric-Furnace Steel on a 10 × 10-in. Mill*

*All 30% per pass. Rolls reset between passes at different speeds. Vacuum A 40 rolling oil. Rolled 25th Jan., 1946*

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Strip No. | Rolling Speed, ft./min. | Reduction in Pass, % | Reduction Overall, % | Mean Thickness before Pass, in. | Mean Thickness after Pass, in. | Mean Width before Pass, in. | Mean Width after Pass, in. | Contact Area, sq. in. | Total Roll Force, tons | Mean Roll Pressure, tons/sq. in. | Rate of Rolling, tons/hr. | Nett Torque per Roll, tons in. | Energy Consumption, h.p.hr./ton | Total Energy, h.p.hr./ton |
| | | (i) *1st Passes* | | | | | | | | | | | | |
| 1 | 6 | 29·4 | 29·4 | 0·0989 | 0·0698 | 2·993 | 3·015 | 1·148 | 51·6 | 44·9 | 0·11 | 8·5 | 12·1 | 12·1 |
| 2 | 5 | 29·2 | 29·2 | 0·0988 | 0·0700 | 2·992 | 3·015 | 1·142 | 51·6 | 45·2 | 0·096 | 8·6 | 12·2 | 12·2 |
| 3 | 99 | 30·4 | 30·4 | 0·0991 | 0·0689 | 2·992 | 3·016 | 1·167 | 55·5 | 47·6 | 1·86 | 9·1 | 13·1 | 13·1 |
| 4 | 98 | 30·5 | 30·5 | 0·0989 | 0·0687 | 2·992 | 3·016 | 1·167 | 55·5 | 47·6 | 1·84 | 9·4 | 13·6 | 13·6 |
| 5 | 235 | 30·2 | 30·2 | 0·0992 | 0·0692 | 2·993 | 3·016 | 1·167 | 56·5 | 48·4 | 4·45 | 9·3 | 13·3 | 13·3 |
| 6 | 234 | 30·1 | 30·1 | 0·0993 | 0·0694 | 2·993 | 3·017 | 1·160 | 56·8 | 48·9 | 4·42 | 9·6 | 13·8 | 13·8 |
| | | (ii) *2nd Passes* | | | | | | | | | | | | |
| 1 | 6·5 | 28·9 | 49·8 | 0·0698 | 0·0496 | 3·015 | 3·031 | 0·963 | 65·3 | 67·8 | 0·08 | 9·3 | 18·5 | 30·6 |
| 2 | 7 | 29·2 | 49·8 | 0·0700 | 0·0496 | 3·015 | 3·030 | 0·965 | 65·8 | 68·2 | 0·09 | 9·3 | 18·5 | 30·7 |
| 3 | 99 | 29·5 | 51·0 | 0·0689 | 0·0486 | 3·016 | 3·032 | 0·962 | 65·1 | 67·7 | 1·32 | 8·6 | 17·5 | 30·6 |
| 4 | 98 | 29·4 | 51·0 | 0·0687 | 0·0485 | 3·016 | 3·033 | 0·962 | 65·5 | 68·1 | 1·31 | 8·8 | 17·9 | 31·5 |
| 5 | 235 | 29·5 | 50·8 | 0·0692 | 0·0488 | 3·016 | 3·034 | 0·968 | 63·6 | 65·7 | 3·19 | 8·7 | 17·4 | 30·7 |
| 6 | 234 | 29·6 | 50·7 | 0·0694 | 0·0489 | 3·017 | 3·034 | 0·968 | 64·1 | 66·3 | 3·18 | 8·6 | 17·2 | 31·0 |
| | | (iii) *3rd Passes* | | | | | | | | | | | | |
| 1 | 7 | 30·0 | 64·9 | 0·0496 | 0·0347 | 3·031 | 3·047 | 0·830 | 80·1 | 96·5 | 0·07 | 8·3 | 23·6 | 54·2 |
| 2 | 7 | 30·2 | 65·0 | 0·0496 | 0·0346 | 3·030 | 3·049 | 0·833 | 80·3 | 96·5 | 0·07 | 8·6 | 24·6 | 55·2 |
| 3 | 100 | 30·2 | 65·8 | 0·0486 | 0·0339 | 3·032 | 3·050 | 0·824 | 69·0 | 83·8 | 0·94 | 7·2 | 20·8 | 51·4 |
| 4 | 100 | 30·1 | 65·7 | 0·0485 | 0·0339 | 3·033 | 3·052 | 0·821 | 69·2 | 84·3 | 0·94 | 7·1 | 20·6 | 52·1 |
| 5 | 234 | 30·5 | 65·8 | 0·0488 | 0·0339 | 3·034 | 3·051 | 0·830 | 67·0 | 80·7 | 2·19 | No reading | ... | ... |
| 6 | 235 | 30·9 | 66·0 | 0·0489 | 0·0338 | 3·034 | 3·051 | 0·836 | 67·6 | 80·9 | 2·19 | ,, | ... | ... |
| | | (iv) *4th Passes* | | | | | | | | | | | | |
| 1 | 7 | 27·9 | 74·7 | 0·0347 | 0·0250 | 3·047 | 3·071 | 0·679 | 108·5 | 159·8 | 0·05 | ,, | ... | ... |
| 2 | 8 | 26·6 | 74·3 | 0·0346 | 0·0254 | 3·049 | 3·072 | 0·661 | 104·2 | 157·5 | 0·06 | ,, | ... | ... |
| 3 | 101 | 30·4 | 76·2 | 0·0339 | 0·0236 | 3·050 | 3·069 | 0·695 | 83·7 | 120·5 | 0·66 | ,, | ... | ... |
| 4 | 101 | 30·1 | 76·0 | 0·0339 | 0·0237 | 3·052 | 3·069 | 0·691 | 84·0 | 121·6 | 0·66 | ,, | ... | ... |
| 5 | 245 | 29·5 | 75·9 | 0·0339 | 0·0239 | 3·051 | 3·068 | 0·685 | 73·7 | 107·6 | 1·63 | ,, | ... | ... |
| 6 | 245 | 29·9 | 76·1 | 0·0338 | 0·0237 | 3·051 | 3·069 | 0·689 | 74·6 | 108·3 | 1·62 | ,, | ... | ... |

TABLE II (*b*)—*Results Obtained by Cold Rolling 3 × 0·10-in., 0·2%-C Electric-Furnace Steel on a 10 × 10-in. Mill*

*All 30% per pass. Rolls reset between passes at different speeds. Vacuum A 40 rolling oil. Rolled 11th Feb., 1946*

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Strip No. | Rolling Speed, ft./min. | Reduction in Pass, % | Reduction Overall, % | Mean Thickness before Pass, in. | Mean Thickness after Pass, in. | Mean Width before Pass, in. | Mean Width after Pass, in. | Contact Area, sq. in. | Total Roll Force, tons | Mean Roll Pressure, tons/sq. in. | Rate of Rolling, tons/hr. | Nett Torque per Roll, tons in. | Energy Consumption, h.p.hr./ton | Total Energy, h.p.hr./ton |
| | | (i) *1st Passes* | | | | | | | | | | | | |
| 1 | 39 | 30·1 | 30·1 | 0·1008 | 0·0704 | 2·994 | 3·019 | 1·172 | 58·0 | 49·5 | 0·75 | 9·9 | 14·0 | 14·0 |
| 2 | 39 | 30·1 | 30·1 | 0·1008 | 0·0704 | 2·994 | 3·019 | 1·172 | 57·6 | 49·2 | 0·75 | 9·7 | 13·7 | 13·7 |
| 3 | 72 | 30·0 | 30·0 | 0·1012 | 0·0708 | 2·995 | 3·017 | 1·170 | 57·0 | 48·7 | 1·39 | 9·1 | 12·7 | 12·7 |
| 4 | 72 | 30·6 | 30·6 | 0·1014 | 0·0705 | 2·993 | 3·016 | 1·181 | 58·9 | 49·8 | 1·38 | 9·2 | 12·9 | 12·9 |
| 5 | 161 | 30·3 | 30·3 | 0·1008 | 0·0703 | 2·993 | 3·017 | 1·172 | 58·2 | 49·6 | 3·11 | 9·9 | 14·0 | 14·0 |
| 6 | 160 | 30·3 | 30·3 | 0·1005 | 0·0701 | 2·991 | 3·017 | 1·172 | 58·5 | 49·8 | 3·07 | 9·5 | 13·4 | 13·4 |
| | | (ii) *2nd Passes* | | | | | | | | | | | | |
| 1 | 39 | 30·2 | 51·3 | 0·074 | 0·0491 | 3·019 | 3·036 | 0·987 | 68·9 | 69·8 | 0·53 | 9·9 | 19·9 | 33·9 |
| 2 | 39 | 30·5 | 51·4 | 0·0704 | 0·0489 | 3·019 | 3·037 | 0·993 | 69·2 | 69·8 | 0·53 | 9·9 | 19·9 | 33·6 |
| 3 | 71 | 30·2 | 51·1 | 0·0708 | 0·0496 | 3·017 | 3·036 | 0·985 | 66·0 | 67·0 | 0·97 | 9·0 | 17·8 | 30·5 |
| 4 | 71 | 30·2 | 51·5 | 0·0705 | 0·0492 | 3·016 | 3·035 | 0·985 | 66·6 | 67·6 | 0·96 | 9·2 | 18·4 | 31·3 |
| 5 | 157 | 29·0 | 50·5 | 0·0703 | 0·0498 | 3·017 | 3·033 | 0·968 | 66·3 | 68·5 | 2·16 | 9·3 | 18·4 | 32·4 |
| 6 | 157 | 29·0 | 50·4 | 0·0701 | 0·0498 | 3·017 | 3·037 | 0·962 | 66·9 | 69·6 | 2·16 | 9·2 | 18·2 | 31·6 |
| | | (iii) *3rd Passes* | | | | | | | | | | | | |
| 1 | 39 | 30·0 | 65·9 | 0·0491 | 0·0344 | 3·036 | 3·054 | 0·825 | 74·1 | 89·8 | 0·37 | 8·7 | 24·8 | 58·7 |
| 2 | 39 | 29·3 | 65·7 | 0·0489 | 0·0346 | 3·037 | 3·052 | 0·813 | 72·7 | 89·4 | 0·38 | 8·5 | 24·0 | 57·6 |
| 3 | 72 | 30·4 | 65·9 | 0·0496 | 0·0345 | 3·036 | 3·052 | 0·837 | 71·5 | 85·4 | 0·68 | 8·2 | 23·6 | 54·1 |
| 4 | 72 | 30·4 | 66·2 | 0·0492 | 0·0343 | 3·035 | 3·053 | 0·831 | 71·8 | 86·3 | 0·67 | 8·2 | 23·7 | 55·0 |
| 5 | 159 | 32·2 | 66·4 | 0·0498 | 0·0339 | 3·033 | 3·052 | 0·858 | 70·8 | 82·5 | 1·49 | 8·6 | 24·8 | 57·2 |
| 6 | 159 | 31·3 | 66·1 | 0·0498 | 0·0342 | 3·037 | 3·055 | 0·849 | 72·0 | 84·8 | 1·50 | 8·6 | 24·6 | 56·2 |
| | | (iv) *4th Passes* | | | | | | | | | | | | |
| 1 | 40 | 28·5 | 75·6 | 0·0344 | 0·0246 | 3·054 | 3·073 | 0·677 | 81·8 | 120·7 | 0·28 | 7·5 | 29·6 | 88·3 |
| 2 | 40 | 27·8 | 75·2 | 0·0346 | 0·0250 | 3·052 | 3·075 | 0·671 | 82·4 | 122·8 | 0·28 | 7·2 | 28·0 | 85·6 |
| 3 | 73 | 29·1 | 75·8 | 0·0345 | 0·0245 | 3·052 | 3·073 | 0·683 | 75·0 | 109·8 | 0·50 | 6·9 | 27·4 | 81·5 |
| 4 | 73 | 28·2 | 75·7 | 0·0343 | 0·0247 | 3·053 | 3·071 | 0·671 | 76·1 | 113·3 | 0·50 | 6·6 | 26·0 | 81·0 |
| 5 | 162 | 31·6 | 77·0 | 0·0339 | 0·0232 | 3·052 | 3·072 | 0·711 | 72·6 | 102·1 | 1·05 | 7·5 | 31·4 | 88·6 |
| 6 | 162 | 31·4 | 76·6 | 0·0342 | 0·0235 | 3·055 | 3·074 | 0·711 | 74·0 | 104·1 | 1·07 | 7·4 | 30·6 | 86·8 |

ft./min. In contrast to this, the results for the last pass show that although the mean roll pressure was decidedly lower at the higher speed, yet a considerably greater reduction was obtained at 240 ft./min. with the same roll setting which only produced 30% reduction at 40 ft./min. Thus in the fourth pass, at 40 ft./min. ,the mean roll pressure was about 120 tons/sq. in. for a 30% reduction, whilst at 240 ft./min. the same roll setting produced almost a 44% reduction at a mean roll pressure of about 93 tons/sq. in.

It was obvious that the next step should be to set the rolls afresh with trial pieces for every pass, so as to eliminate the variable reduction.

### *Extended Tests on 3 × 0·1-in. Annealed 0·2%-C Steel Strip*

In repeating the above tests with the rolls reset for each pass, the opportunity was taken to increase the number of speeds at which observations were taken, the selected values being 8, 40, 70, 100, 160, and 240 ft./min. These were the speeds at which the mill was set before entering the test length ; there was generally a drop in speed during rolling, which accounts for the plotted points not being on the ordinates corresponding to the nominal values in every case.

The results of these tests are given in Table II and shown in Figs. 2 and 3. They point to general conclusions which have been found to hold qualitatively in all the subsequent tests. These conclusions are :

(*a*) In the earlier passes, when the material is thick and comparatively soft, the roll force and torque are substantially independent of speed.

(*b*) When the material is strongly work-hardened, and is becoming thin, there is a sharp falling-off in roll pressure as the speed is increased. The mean roll pressure (and likewise the roll force) may be 40–50% higher at

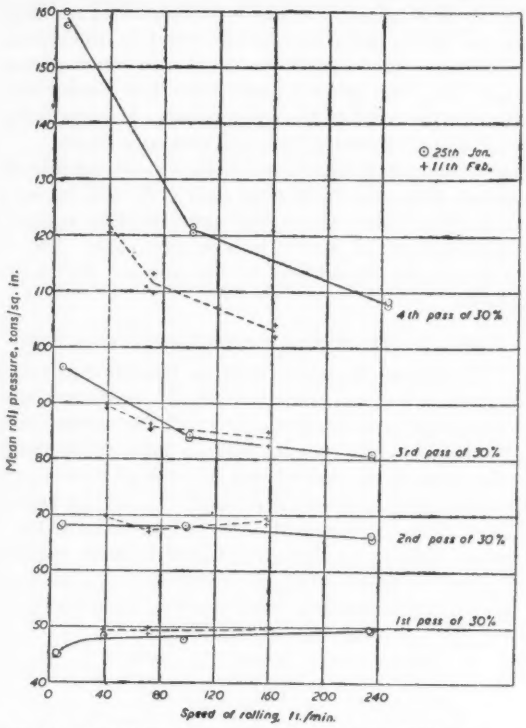


FIG. 2—Variation of mean roll pressure with speed; 0·2%-C electric-furnace steel, coils 65 and 66, short lengths of 3 × 0·1-in. strip

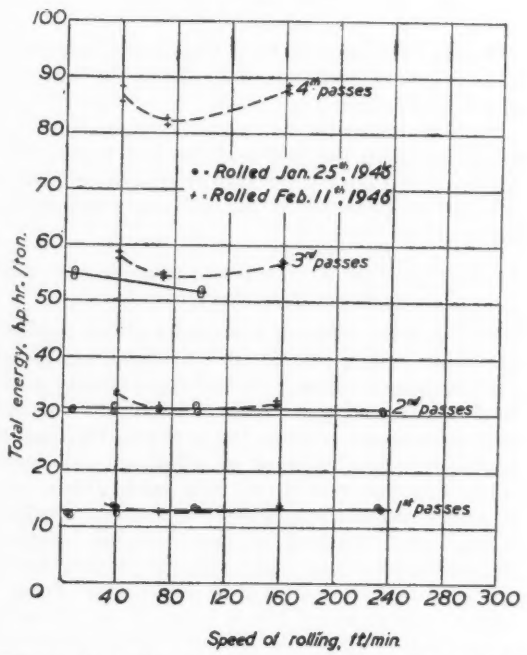


FIG. 3—Variation of total energy with speed; 0·2%-C electric-furnace steel

a few feet per minute compared with, say, 250 ft./min.

(*c*) Alternatively, if the rolls are set to give a definite strip gauge at low speed (*e.g.*, when starting up a coil of strip) and the mill is then accelerated, the gauge will decrease. When strip is being rolled, the roll separating force gives rise to an elastic extension of the mill frame, etc. If, therefore, the roll force decreases, the elastic extension of the mill structure will correspondingly decrease, bringing the rolls closer together, until a new equilibrium is reached.

Only qualitative conclusions could properly be drawn from these tests, as will be evident from the plotted results in Fig. 2. The full lines connect points representing tests at 8, 100, and 240 ft./min. nominal speeds. These tests were all made on the same date. The actual experimental results are given in Table II. When a fortnight later further tests were made at 40, 70, and 160 ft./min. to supplement the information previously obtained, it was found that the new points (connected by the dotted lines), although exhibiting the same

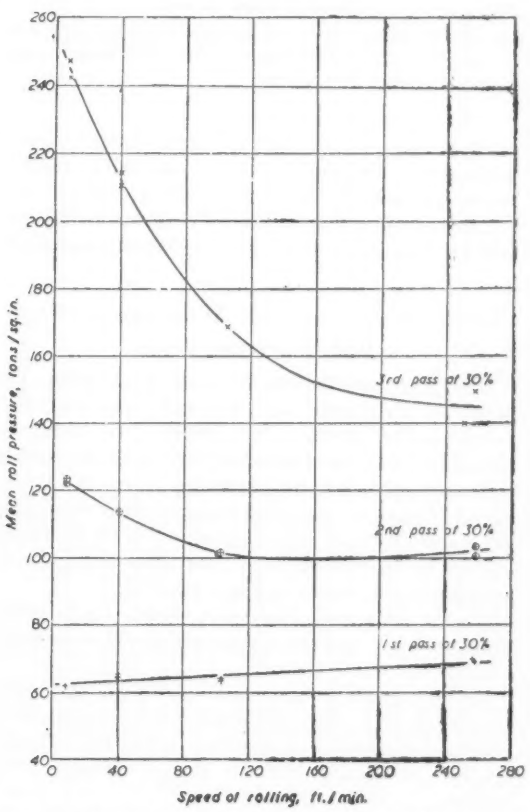


FIG. 4—Variation of mean roll pressure with speed; 0·07%-C rimming steel, coil 24, short lengths of $3\frac{1}{8}$ × 0·032-in. strip

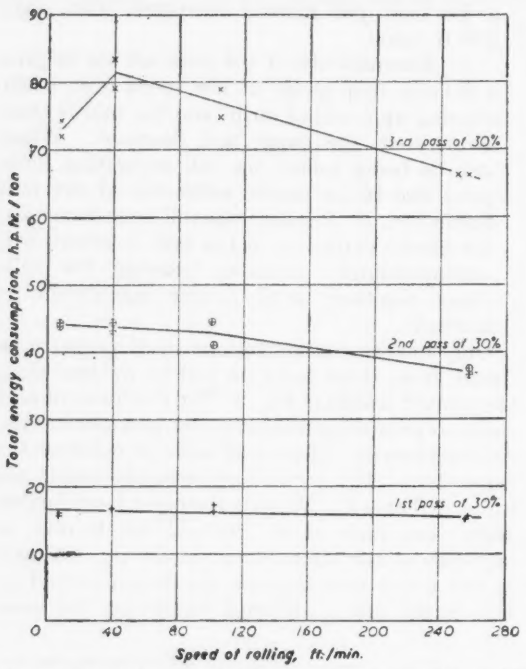


FIG. 5—Variation of total energy consumption with speed ; 0·07%-C rimming steel, coil 24, short length of $3\frac{1}{8} \times 0{\cdot}032$-in. strip

tendency as before, did not agree quantitatively with them, although all the controllable factors were apparently the same. This matter was satisfactorily explained in subsequent tests, and will be dealt with later in this paper (page 387).

## TESTS ON $3\frac{1}{8} \times 0{\cdot}03$-IN. ANNEALED 0·07%-C RIMMING-STEEL STRIP

The foregoing results showed that when the strip was thin and hard, the roll force was very considerably affected by speed. In order to determine whether this effect was more dependent on the degree of work-hardening or on the thickness of the strip, the next series of tests was made on a soft steel initially only about 0·03 in. thick.

The mean roll pressure and total energy consumption are shown in Figs. 4 and 5.

In the first pass, there is a slight rise in mean roll pressure, but the torque remained essentially constant.

In the second, and particularly in the third pass, however, the roll pressure falls rapidly with increasing speed, and the same effect to a smaller extent is shown by the energy consumption figures.

These tests show that the speed effect is not only dependent on strip thickness but on a combination of thickness and hardness. Thus, the thin soft steel strip in these tests showed no drop in roll force with increasing speed in the initial condition, but showed the effect at a much earlier pass (*i.e.*, the second pass) than the harder but thicker material of the earlier tests. It is probable that the diameter of the roll is also a factor, *i.e.*, the diameter/thickness ratio should be considered rather than the thickness only. It will be seen from Fig. 5 that the energy consumption is again independent of speed in the first pass, but is increasingly dependent in the second and third passes.

## TESTS ON HIGH CONDUCTIVITY COPPER STRIP

The remainder of the tests on the effect of speed variation were made on specially prepared high conductivity copper strip.* All the strips were 3·0 in. wide but were initially in three thicknesses. The tests were carried out according to the procedure already described ; that is to say, by taking twice as many strips of annealed material as there were speeds to be investigated, and making successive passes of equal reduction per pass, until no further reduction was possible. This was done for the following sets of conditions :

| Dimensions of Strip, in. | Reduction per Pass, % | No. of Passes | Total Reduction, % |
|---|---|---|---|
| (*a*) $3 \times 0{\cdot}1$ | 30 | 7 | 92 |
| (*b*) $3 \times 0{\cdot}05$ | 30 | 5 | 85 |
| (*c*) $3 \times 0{\cdot}075$ | 20 | 11 | 92 |
| (*d*) $3 \times 0{\cdot}075$ | 30 | 6 | 88 |
| (*e*) $3 \times 0{\cdot}075$ | 40 | 4 | 87 |
| (*f*) $3 \times 0{\cdot}075$ | 2, 5, 10, 50, 60, 70, 80 and 90 | 1 each | |

Each of the above sets of tests was carried out at a representative selection of speeds between 5 and 300 ft./min.

Since the most interesting phenomena show up most clearly in the first and the last passes, the whole of the curves for the intermediate passes are not reproduced in the following figures in every case.

### *Discussion of the Results for Copper—0·1-in. and 0·05-in. thick Copper Strip*

In Fig. 6 the values of mean roll pressure against speed for copper initially 0·1 in. thick are given for all passes. This material was initially both fairly thick and quite soft. The results for the first four passes confirm the previous findings in that speed has little or no effect on roll force while the material is soft and fairly thick. In the later passes the speed effect becomes progressively more marked as the material becomes thinner and harder—again as in the previous tests. At the seventh pass it will be seen that a ' hump ' has appeared around 100 ft./min. It was thought

* Kindly supplied by Messrs. I.C.I., Ltd. (Metals Division).

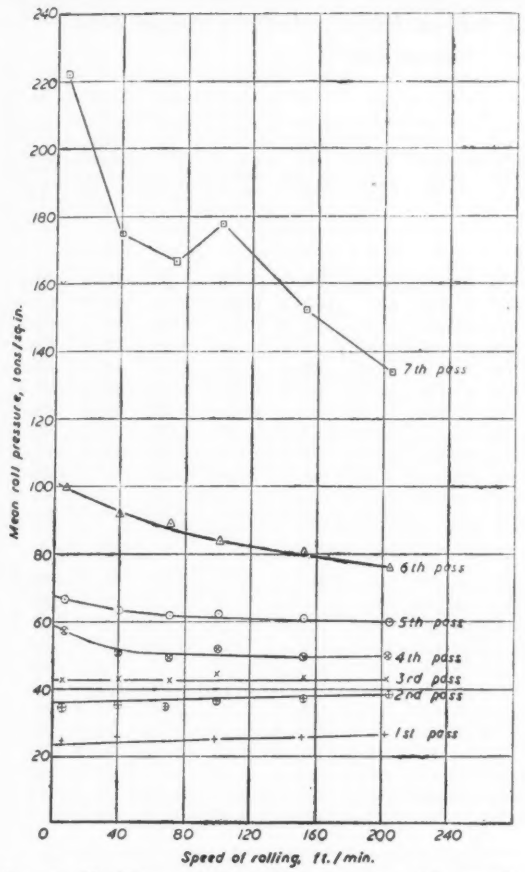


FIG. 6—Variation of mean roll pressure with speed; H.C. copper strip, 0·10-in. thick, short lengths. All reductions 30% per pass

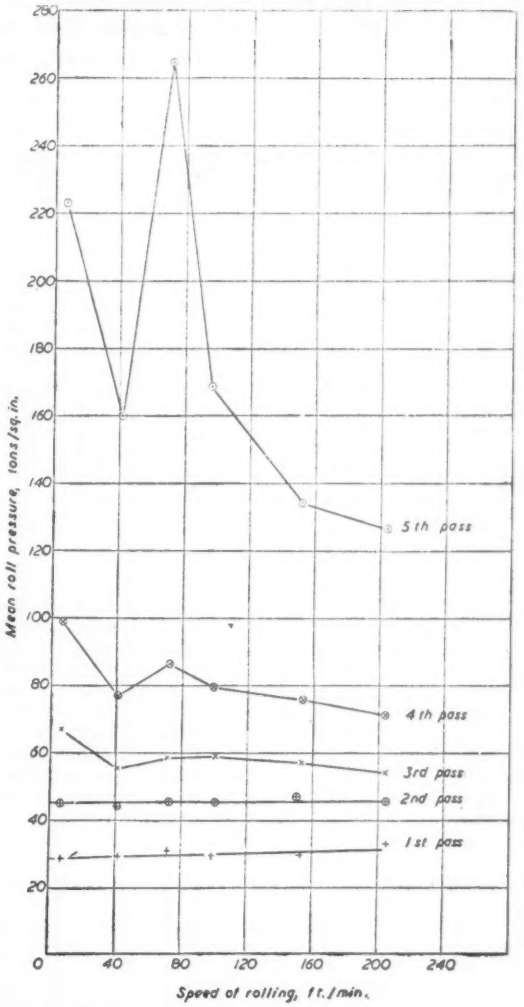


FIG. 7—Variation of mean roll pressure with speed; H.C. copper strip, 0·05-in. thick, short lengths. All reduction 30% per pass

at first that the meter readings were incorrect, but reference to Fig. 7, which gives similar curves for material initially 0·05 in. thick, will show that an even greater scatter is obtained in the fourth and fifth passes in those tests.

In Tables III and IV the results obtained for the last passes are shown. A study of the figures in columns 5 and 6 will show that most of the peculiar values of roll force arose where the thickness of the strip entering the pass was either thicker or thinner than the correct setting. In a series of successive passes it is difficult to keep the strip thicknesses exactly alike under the exacting conditions. It will also be seen that an exceptionally high value of roll force occurs when a strip which was initially thinner than the normal for the pass also received a heavier reduction than the desired 30% for the pass.

The explanation probably is that the minimum thickness for the particular material and roll diameter in these tests is not much less than 0·007 in., which is roughly the thickness reached in these tests. The roll flattening is so great that little more reduction can be made, and hence in attempting a 30% reduction when approaching this thickness, the roll force is mainly made up of the elastic compression force between the rolls, and may bear little relation to the force required for deforming the material.

This phenomenon has been observed previously by Keller[10] and a theoretical explanation was given. Examination of this reference will show that the screw-down pressure can be varied considerably once the minimum thickness is approached, without making any essential change in thick ness.

TABLE III—*Results of Cold Rolling Tests on 3 × 0·10-in. High-Conductivity Copper Strip*

*All reductions 30% per pass. Vacuum A 40 oil*

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Strip No. | Rolling Speed, ft./min. | Reduction in Pass, % | Reduction Overall, % | Mean Thickness before Pass, in. | Mean Thickness after Pass, in. | Mean Width before Pass, in. | Mean Width after Pass, in. | Contact Area, sq. in. | Total Roll Force, tons | Mean Roll Pressure, tons/sq. in. | Rate of Rolling, tons/hr. | Nett Torque per Roll, tons/in. | Energy Consumption, h.p.hr./ton | Total Energy, h.p.hr./ton |
| | | (i) *6th Passes* | | | | | | | | | | | | |
| 1 | 7·1 | 32·6 | 88·7 | 0·0172 | 0·0116 | 3·053 | 3·078 | 0·509 | 50·2 | 98·7 | 0·03 | 2·20 | 16·4 | 62·6 |
| 2 | 7·0 | 31·4 | 88·6 | 0·0169 | 0·0116 | 3·059 | 3·084 | 0·498 | 50·1 | 100·5 | 0·03 | 2·20 | 16·4 | 61·6 |
| 3 | 40 | 32·9 | 88·8 | 0·0170 | 0·0114 | 3·053 | 3·074 | 0·508 | 46·0 | 90·6 | 0·15 | 2·46 | 18·7 | 62·4 |
| 4 | 40 | 31·3 | 88·4 | 0·0169 | 0·0116 | 3·056 | 3·068 | 0·496 | 45·6 | 92·0 | 0·15 | 2·29 | 17·1 | 63·5 |
| 5 | 71 | 33·7 | 89·4 | 0·0166 | 0·0110 | 3·051 | 3·069 | 0·508 | 45·2 | 89·0 | 0·25 | 2·43 | 18·9 | 63·4 |
| 6 | 71 | 34·1 | 89·0 | 0·0167 | 0·0110 | 3·049 | 3·068 | 0·514 | 45·2 | 88·0 | 0·25 | 2·43 | 18·9 | 63·6 |
| 7 | 102 | 33·7 | 88·9 | 0·0169 | 0·0112 | 3·046 | 3·067 | 0·514 | 43·0 | 83·7 | 0·36 | 2·37 | 18·4 | 63·7 |
| 8 | 102 | 34·1 | 88·9 | 0·0170 | 0·0112 | 3·048 | 3·062 | 0·517 | 42·8 | 82·8 | 0·36 | 2·32 | 18·1 | 66·7 |
| 9 | 153 | 31·9 | 88·8 | 0·0166 | 0·0113 | 3·048 | 3·064 | 0·495 | 39·2 | 79·2 | 0·56 | 2·36 | 17·9 | 67·9 |
| 10 | 153 | 32·5 | 88·9 | 0·0166 | 0·0112 | 3·050 | 3·065 | 0·500 | 40·5 | 81·0 | 0·54 | 2·26 | 17·6 | 66·3 |
| 11 | 205 | 32·8 | 88·5 | 0·0177 | 0·0119 | 3·054 | 3·071 | 0·519 | 39·2 | 75·5 | 0·77 | 2·42 | 17·8 | 63·9 |
| 12 | 205 | 33·1 | 88·6 | 0·0172 | 0·0115 | 3·052 | 3·071 | 0·514 | 39·0 | 75·9 | 0·75 | 2·15 | 16·3 | 62·4 |
| | | (ii) *7th Passes* | | | | | | | | | | | | |
| 1 | 7·1 | 29·3 | 92·0 | 0·0116 | 0·0082 | 3·078 | 3·111 | 0·402 | 88·1 | 219·0 | 0·02 | 2·20 | 22·9 | 85·5 |
| 2 | 7·1 | 27·6 | 91·6 | 0·0116 | 0·0084 | 3·084 | 3·117 | 0·391 | 88·1 | 225·0 | 0·02 | 2·35 | 23·9 | 85·7 |
| 3 | 40 | 27·2 | 92·0 | 0·0114 | 0·0083 | 3·074 | 3·099 | 0·383 | 68·5 | 178·8 | 0·11 | 1·85 | 19·1 | 81·5 |
| 4 | 40 | 29·3 | 91·8 | 0·0116 | 0·0082 | 3·068 | 3·102 | 0·401 | 68·5 | 170·8 | 0·11 | 1·92 | 20·1 | 83·5 |
| 5 | 73 | 32·7 | 92·9 | 0·0110 | 0·0074 | 3·069 | 3·094 | 0·410 | 68·2 | 166·2 | 0·17 | 2·21 | 25·5 | 88·9 |
| 6 | 73 | 32·7 | 92·6 | 0·0110 | 0·0074 | 3·068 | 3·094 | 0·410 | 68·4 | 166·6 | 0·17 | 1·96 | 22·6 | 81·1 |
| 7 | 102 | 37·5 | 93·0 | 0·0112 | 0·0070 | 3·067 | 3·100 | 0·443 | 78·0 | 176·1 | 0·23 | 2·92 | 35·1 | 98·8 |
| 8 | 102 | 36·6 | 93·0 | 0·0112 | 0·0071 | 3·062 | 3·093 | 0·437 | 78·3 | 179·3 | 0·23 | 2·70 | 32·5 | 99·2 |
| 9 | 153 | 34·5 | 92·8 | 0·0113 | 0·0074 | 3·064 | 3·085 | 0·426 | 63·6 | 149·0 | 0·37 | 2·66 | 30·6 | 98·5 |
| 10 | 153 | 33·0 | 92·6 | 0·0112 | 0·0075 | 3·065 | 3·090 | 0·415 | 64·3 | 155·0 | 0·37 | 2·74 | 31·6 | 97·9 |
| 11 | 205 | 29·4 | 91·9 | 0·0119 | 0·0084 | 3·071 | 3·088 | 0·403 | 52·8 | 131·0 | 0·55 | 1·83 | 18·6 | 82·5 |
| 12 | 205 | 27·0 | 91·7 | 0·0115 | 0·0084 | 3·071 | 3·096 | 0·382 | 51·8 | 135·6 | 0·55 | 1·66 | 16·9 | 79·3 |

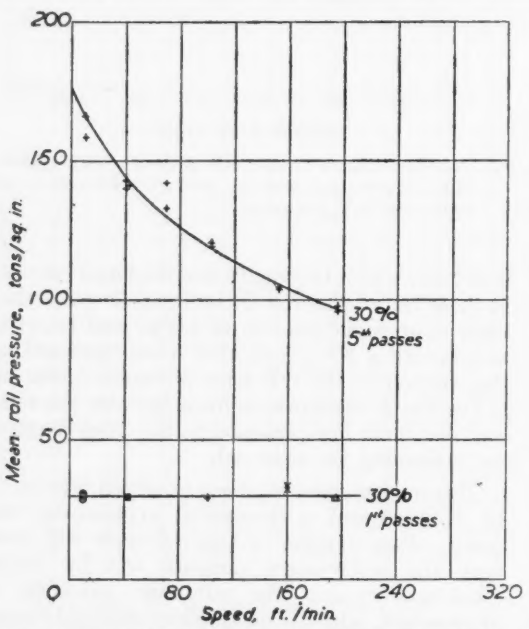


FIG. 8—Variation of mean roll pressure with speed of rolling; H.C. copper, 0·05-in. strip

*Special Tests on High Conductivity Copper*

To check this point further, a number of strips of 0·05-in. material were rolled down at 40 ft./min. in approximately 30% passes to a final thickness of about 0·012 in., without noting any readings of intermediate passes, and aiming at a uniform thickness of all the strips when the final thickness was reached.

The strips prepared in this way were then rolled in pairs at various speeds to give a 30% reduction as near as possible. The results are given in Table V and Fig. 8. It will be seen that the considerable differences in roll pressure have largely been smoothed out by following this treatment, and this shows that the above explanation of the cause of the scatter is probably the correct one.

In the previous tests with the 0·05-in. material, an exceptionally high reading of mean roll pressure was obtained at a speed of 70 ft./min. A new test was done at this speed, repeating the initial thickness and final reduction of the previous test (*i.e.*, strips Nos. 5 and 6 in Table IV, 5th passes on 0·05-in. strip) as near as possible, and noting the roll force.

TABLE IV—*Results of Cold Rolling Tests on 3 × 0·05-in. High-Conductivity Copper Strip*

*All reductions 30% per pass. Vacuum A 40 oil*

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Strip No. | Rolling speed, ft./in. | Reduction in Pass, % | Reduction, Overall, % | Mean Thickness before Pass, in. | Mean Thickness after Pass, in. | Mean Width before Pass, in. | Mean Width after Pass, in. | Contact Area, sq. in. | Total Roll Force, tons | Mean Roll Pressure, tons/sq. in. | Rate of Rolling tons/hr. | Nett Torque per Roll tons ins. | Energy Consumption h.p./hr./ton | Total Energy, h.p./hrs. ton |
| | | (i) *4th Passes* | | | | | | | | | | | | |
| 1 | 7·3 | 30·0 | 77·0 | 0·0171 | 0·0120 | 3·033 | 3·050 | 0·484 | 47·8 | 98·8 | 0·03 | 2·06 | 14·9 | 43·5 |
| 2 | 7·2 | 30·0 | 77·1 | 0·0170 | 0·0119 | 3·032 | 3·048 | 0·484 | 48·1 | 99·4 | 0·03 | 2·06 | 15·1 | 43·2 |
| 3 | 41 | 31·7 | 76·1 | 0·0183 | 0·0125 | 3·026 | 3·039 | 0·512 | 39·2 | 76·6 | 0·16 | 2·10 | 14·7 | 42·0 |
| 4 | 41 | 31·3 | 76·3 | 0·0182 | 0·0125 | 3·025 | 3·039 | 0·509 | 39·4 | 77·4 | 0·16 | 2·10 | 14·7 | 40·9 |
| 5 | 72 | 38·4 | 80·4 | 0·0164 | 0·0101 | 3·030 | 3·048 | 0·538 | 47·0 | 87·4 | 0·23 | 2·64 | 22·8 | 50·9 |
| 6 | 72 | 40·5 | 81·1 | 0·0163 | 0·0097 | 3·030 | 3·047 | 0·550 | 46·8 | 85·1 | 0·22 | 2·64 | 23·7 | 52·1 |
| 7 | 99 | 34·7 | 78·5 | 0·0170 | 0·0111 | 3·032 | 3·045 | 0·520 | 40·6 | 78·1 | 0·35 | 2·16 | 17·0 | 45·4 |
| 8 | 99 | 33·2 | 78·0 | 0·0169 | 0·0113 | 3·033 | 3·046 | 0·504 | 40·9 | 81·2 | 0·35 | 2·08 | 16·1 | 44·4 |
| 9 | 154 | 33·9 | 77·6 | 0·0174 | 0·0115 | 3·032 | 3·042 | 0·519 | 38·6 | 74·4 | 0·56 | 2·26 | 17·1 | 44·9 |
| 10 | 154 | 31·8 | 77·3 | 0·0173 | 0·0118 | 3·031 | 3·042 | 0·501 | 38·5 | 76·8 | 0·57 | 2·01 | 14·9 | 42·2 |
| 11 | 204 | 33·3 | 78·3 | 0·0168 | 0·0112 | 3·032 | 3·045 | 0·504 | 36·1 | 71·6 | 0·72 | 2·08 | 16·2 | 40·7 |
| 12 | 204 | 33·3 | 76·6 | 0·0168 | 0·0112 | 3·032 | 3·047 | 0·504 | 35·6 | 70·6 | 0·72 | 1·91 | 14·9 | 39·6 |
| | | (ii) *5th Passes* | | | | | | | | | | | | |
| 1 | 7·1 | 30·0 | 84·0 | 0·0120 | 0·0084 | 3·050 | 3·089 | 0·408 | 90·1 | 220·7 | 0·02 | 1·75 | 18·0 | 61·4 |
| 2 | 7·2 | 29·4 | 83·8 | 0·0119 | 0·0084 | 3·048 | 3·084 | 0·404 | 90·9 | 225·0 | 0·02 | 1·17 | 12·0 | 55·2 |
| 3 | 41 | 32·0 | 83·8 | 0·0125 | 0·0085 | 3·039 | 3·071 | 0·431 | 69·9 | 162·5 | 0·11 | 2·34 | 23·8 | 65·8 |
| 4 | 42 | 32·0 | 83·9 | 0·0125 | 0·0085 | 3·039 | 3·068 | 0·431 | 67·7 | 157·3 | 0·11 | 2·37 | 24·1 | 66·0 |
| 5 | 71 | 30·7 | 86·4 | 0·0101 | 0·0070 | 3·048 | 3·086 | 0·381 | 96·2 | 252·5 | 0·16 | 2·52 | 31·0 | 81·9 |
| 6 | 71 | 26·8 | 86·2 | 0·0097 | 0·0071 | 3·047 | 3·087 | 0·347 | 96·2 | 277·0 | 0·16 | 2·43 | 29·5 | 81·6 |
| 7 | 92 | 31·6 | 85·2 | 0·0111 | 0·0076 | 3·045 | 3·078 | 0·404 | 69·8 | 172·6 | 0·22 | 2·30 | 26·1 | 71·6 |
| 8 | 99 | 34·5 | 85·5 | 0·0113 | 0·0074 | 3·046 | 3·078 | 0·426 | 70·2 | 164·8 | 0·23 | 2·58 | 30·2 | 74·6 |
| 9 | 152 | 33·9 | 85·2 | 0·0115 | 0·0076 | 3·042 | 3·063 | 0·423 | 56·2 | 133·0 | 0·37 | 2·18 | 24·9 | 69·8 |
| 10 | 152 | 32·2 | 84·6 | 0·0118 | 0·0080 | 3·042 | 3·066 | 0·417 | 56·3 | 135·2 | 0·38 | 2·09 | 22·7 | 64·9 |
| 11 | 204 | 33·9 | 85·6 | 0·0112 | 0·0074 | 3·045 | 3·067 | 0·418 | 52·7 | 126·3 | 0·48 | 2·07 | 24·2 | 65·0 |
| 12 | 204 | 34·8 | 84·9 | 0·0112 | 0·0073 | 3·047 | 3·075 | 0·426 | 53·8 | 126·3 | 0·47 | 1·98 | 23·5 | 63·1 |

TABLE V—*Results of Special Tests on Cold Rolling 3 × 0·052-in. High Conductivity Copper Strip*

*Using a 10 × 10-in. Mill, and A 40 Rolling Oil*

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
|---|---|---|---|---|---|---|---|---|---|---|
| Strip No. | Speed, ft./min. | Reduction in Pass, % | Reduction Overall, % | Thickness before Pass, in. | Thickness after Pass, in. | Width before Pass, in. | Width after Pass, in. | Contact Area, sq. in. | Total Roll Force, tons | Mean Roll Pressure, tons/sq. in. |
| 1 | 42 | 27·4 | 82·6 | 0·0124 | 0·0090 | 3·058 | 3·082 | 0·398 | 54·3 | 136·5 |
| 2 | 42 | 28·8 | 82·9 | 0·0125 | 0·0089 | 3·058 | 3·081 | 0·410 | 57·8 | 141·0 |
| 3 | 70 | 29·8 | 83·6 | 0·0121 | 0·0085 | 3·060 | 3·085 | 0·410 | 54·5 | 133·0 |
| 4 | 70 | 33·4 | 84·6 | 0·0120 | 0·0080 | 3·059 | 3·087 | 0·431 | 61·3 | 142·0 |
| 5 | 10 | 30·0 | 82·6 | 0·0129 | 0·0090 | 3·056 | 3·086 | 0·426 | 67·5 | 158·5 |
| 6 | 10 | 28·0 | 82·6 | 0·0125 | 0·0090 | 3·060 | 3·088 | 0·404 | 67·0 | 166·0 |
| 7 | 103 | 31·1 | 84·2 | 0·0119 | 0·0082 | 3·050 | 3·074 | 0·414 | 49·8 | 120·5 |
| 8 | 103 | 31·7 | 84·2 | 0·0120 | 0·0082 | 3·047 | 3·071 | 0·420 | 50·3 | 120·0 |
| 9 | 153 | 30·0 | 84·0 | 0·0119 | 0·0083 | 3·051 | 3·069 | 0·408 | 42·3 | 104·0 |
| 10 | 153 | 30·0 | 84·4 | 0·0116 | 0·0081 | 3·051 | 3·067 | 0·402 | 42·0 | 104·5 |
| 11 | 196 | 31·8 | 83·9 | 0·0123 | 0·0084 | 3·055 | 3·072 | 0·426 | 40·8 | 95·8 |
| 12 | 196 | 31·4 | 84·0 | 0·0121 | 0·0083 | 3·054 | 3·072 | 0·420 | 41·0 | 97·7 |
| 13 | 40 | 30·7 | 83·1 | 0·0127 | 0·0088 | 3·056 | 3·086 | 0·426 | 59·8 | 140·0 |
| 14 | 40 | 30·0 | 83·1 | 0·0126 | 0·0088 | 3·055 | 3·081 | 0·420 | 60·0 | 143·0 |
| 15 | 70 | 30·0 | 87·1 | 0·0095 | 0·0067 | 3·077 | 3·113 | 0·364 | 82·5 | 227·0 |
| 16 | 70 | 30·0 | 86·7 | 0·0098 | 0·0069 | 3·078 | 3·109 | 0·370 | 83·0 | 224·0 |

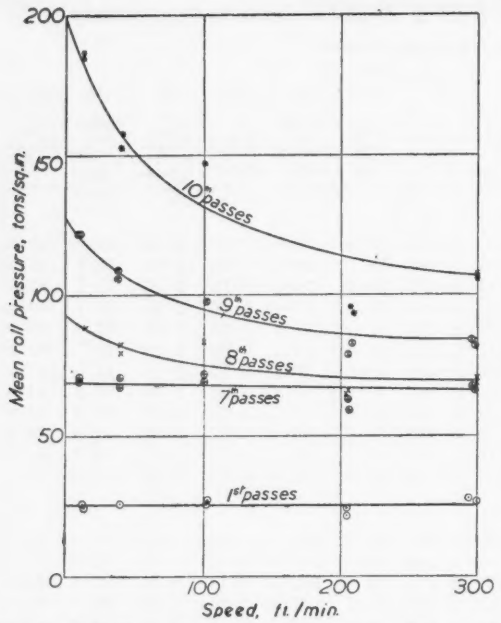


FIG. 9—Variation of mean roll pressure with speed; H.C. copper, 0·075-in. strip. All reductions 20% per pass

The following result was obtained (*see* Table V, strips Nos. 15 and 16) :

Initial thickness = 0·0098 in.
Final thickness = 0·0069 in.
Reduction in pass = 29·6%
Speed = 70 ft./min.
Mean width = 3·094 in.
Area of contact = 0·370 sq. in.
Total roll force = 83·0 tons
Mean roll pressure = 224 tons/sq. in.

These figures confirm, within the accuracy of the tests at these extreme conditions, that the previous results were true observations and not errors in the instruments.

### *Results for 0·075-in. Strip*

In Figs. 9 and 10 various values of mean roll pressure are shown for the first pass and the later passes for copper strip initially 0·075 in. thick. The 20%, 30%, 40%, and 60% passes show the same characteristics as in the other tests, but the 90% single passes are interesting in that these are first passes on an initially soft and thick strip. However, the final thickness is within the range of that where the speed effect is apparent, *i.e.*, about 0·0075 in., and Fig. 10 shows that there is a decrease of 45% in roll pressure as the speed increases.

The more important results are given in Table VI, and Fig. 11 gives the total energy consumption (column 13). It appears that the energy consumption passes through a minimum at a speed below 300 ft./min. in these tests. The first passes of more normal reduction show no influence of speed on energy consumption.

### EFFECT OF SPEED ON STRIP GAUGE

In a few of the tests the screw-down setting was not altered when the speed was changed (*see* Tables I and VIII). These tests therefore approach the conditions of normal rolling during change of speed; for instance, during acceleration and deceleration. In Fig. 12 the variation of gauge from that at the highest speed reached is expressed as a percentage of the gauge at that speed. These tests show that, even over a small range of speed, the exit gauge changes very considerably.

It is not possible to compare these results quantitatively with those of Mohler,[2] since the variation will be a function of the initial thickness and the reduction in the pass, and of the roll diameter, all of which were different in Mohler's tests, but it will be found that the variations are of the same order of magnitude. Mohler puts forward several possible explanations of the speed effect, but from the discussion which follows later in this paper, and from the experimental data already given, none of these explanations would appear to be correct.

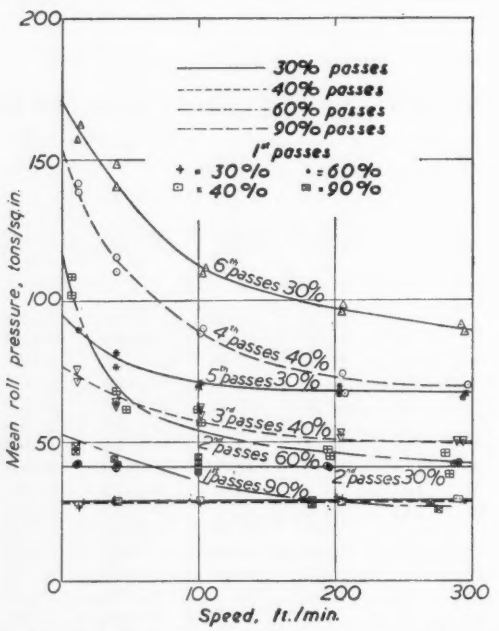


FIG. 10—Variation of mean roll pressure with speed; H.C. copper, 0·075-in. strip. 30, 40, 60, and 90% passes

TABLE VI (*a*)—*Results of Cold Rolling Tests on 3 × 0·075-in. High-Conductivity Copper Strip, at Various Speeds and Passes*

*Using a 10 × 10-in. Mill, and A 40 Rolling Oil—1st, 7th, 8th, 9th, and 10th Passes of 20% Reduction*

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Strip No. | Speed, ft./min. | Reduction in Pass, % | Reduction Overall, % | Thickness before Pass, in. | Thickness after Pass, in. | Width before Pass, in. | Width after Pass, in. | Contact Area, sq. in. | Total Roll Force, tons | Mean Roll Pressure, tons/sq. in. | Total Energy, h.p.hr./ton |
| | | (i) *20% 1st Passes* | | | | | | | | | |
| 1 | 12·8 | 20·3 | 20·3 | 0·0760 | 0·0606 | 2·996 | 3·005 | 0·828 | 20·6 | 24·9 | 2·54 |
| 2 | 12·4 | 21·1 | 21·1 | 0·0773 | 0·0610 | 2·998 | 3·006 | 0·852 | 22·1 | 25·9 | 2·86 |
| 3 | 40 | 19·0 | 19·0 | 0·0751 | 0·0608 | 3·033 | 3·033 | 0·806 | 20·6 | 25·5 | 2·41 |
| 4 | 40 | 19·2 | 19·2 | 0·0750 | 0·0606 | 3·033 | 3·033 | 0·806 | 20·6 | 25·5 | 2·59 |
| 5 | 103 | 20·1 | 20·1 | 0·0761 | 0·0608 | 3·009 | 3·012 | 0·828 | 21·6 | 26·1 | 2·59 |
| 6 | 103 | 19·7 | 19·7 | 0·0731 | 0·0587 | 3·010 | 3·014 | 0·804 | 21·6 | 26·9 | 2·54 |
| 7 | 205 | 19·0 | 19·0 | 0·0758 | 0·0614 | 3·001 | 3·010 | 0·800 | 17·4 | 21·8 | 1·69 |
| 8 | 205 | 19·1 | 19·1 | 0·0749 | 0·0606 | 2·996 | 3·001 | 0·798 | 19·4 | 24·3 | 2·23 |
| 9 | 300 | 20·1 | 20·1 | 0·0761 | 0·0608 | 3·005 | 3·015 | 0·828 | 22·2 | 26·8 | 2·66 |
| 10 | 294 | 20·0 | 20·0 | 0·0761 | 0·0609 | 3·004 | 3·013 | 0·825 | 23·1 | 28·0 | 2·43 |
| | | (ii) *20% 7th Passes* | | | | | | | | | |
| 1 | 9·9 | 20·0 | 79·0 | 0·0200 | 0·0160 | 3·036 | 3·046 | 0·429 | 30·4 | 70·8 | 36·17 |
| 2 | 10·1 | 20·9 | 79·4 | 0·0201 | 0·0159 | 3·039 | 3·046 | 0·438 | 30·4 | 69·5 | 36·14 |
| 3 | 40 | 20·5 | 78·8 | 0·0200 | 0·0159 | 3·058 | 3·066 | 0·435 | 30·9 | 71·0 | 36·81 |
| 4 | 40 | 20·9 | 78·8 | 0·0201 | 0·0159 | 3·056 | 3·063 | 0·441 | 29·9 | 67·7 | 36·08 |
| 5 | 101 | 21·1 | 79·8 | 0·0194 | 0·0153 | 3·041 | 3·047 | 0·432 | 30·1 | 69·7 | 25·87 |
| 6 | 101 | 20·0 | 79·2 | 0·0190 | 0·0152 | 3·042 | 3·049 | 0·417 | 30·1 | 72·2 | 26·69 |
| 7 | 206 | 19·7 | 79·5 | 0·0193 | 0·0155 | 3·039 | 3·050 | 0·417 | 26·3 | 63·1 | 31·63 |
| 8 | 207 | 21·4 | 79·5 | 0·0196 | 0·0154 | 3·037 | 3·045 | 0·438 | 25·9 | 59·1 | 35·09 |
| 9 | 298 | 19·8 | 79·3 | 0·0197 | 0·0158 | 3·051 | 3·061 | 0·425 | 28·2 | 66·4 | 45·30 |
| 10 | 297 | 19·2 | 79·0 | 0·0198 | 0·0160 | 3·046 | 3·054 | 0·417 | 28·2 | 67·6 | 46·09 |
| | | (iii) *20% 8th Passes* | | | | | | | | | |
| 1 | 14·1 | 20·0 | 83·1 | 0·0160 | 0·0128 | 3·046 | 3·057 | 0·384 | 33·9 | 88·3 | 44·59 |
| 2 | 14·1 | 20·1 | 83·5 | 0·0159 | 0·0127 | 3·046 | 3·056 | 0·384 | 33·9 | 88·3 | 44·83 |
| 3 | 40 | 18·8 | 82·8 | 0·0159 | 0·0129 | 3·066 | 3·072 | 0·375 | 29·9 | 79·7 | 43·90 |
| 4 | 40 | 18·8 | 82·8 | 0·0159 | 0·0129 | 3·063 | 3·073 | 0·375 | 30·9 | 82·4 | 43·44 |
| 5 | 101 | 19·0 | 83·7 | 0·0153 | 0·0124 | 3·047 | 3·060 | 0·366 | 30·6 | 83·6 | 33·46 |
| 6 | 101 | 19·1 | 83·2 | 0·0152 | 0·0123 | 3·049 | 3·057 | 0·366 | 30·6 | 83·6 | 32·61 |
| 7 | 206 | 20·0 | 83·6 | 0·0155 | 0·0124 | 3·050 | 3·054 | 0·378 | 24·9 | 65·9 | 36·23 |
| 8 | 205 | 20·8 | 83·8 | 0·0154 | 0·0122 | 3·045 | 3·053 | 0·384 | 24·9 | 64·9 | 42·11 |
| 9 | 300 | 19·0 | 83·3 | 0·0158 | 0·0128 | 3·061 | 3·068 | 0·374 | 26·2 | 70·1 | 51·16 |
| 10 | 300 | 19·4 | 83·1 | 0·0160 | 0·0129 | 3·054 | 3·062 | 0·379 | 26·2 | 69·1 | 50·45 |
| | | (iv) *20% 9th Passes* | | | | | | | | | |
| 1 | 10·8 | 19·5 | 86·5 | 0·0128 | 0·0103 | 3·057 | 3·070 | 0·340 | 41·5 | 122·1 | 52·87 |
| 2 | 11·1 | 19·7 | 86·9 | 0·0127 | 0·0102 | 3·056 | 3·070 | 0·340 | 41·5 | 122·1 | 54·91 |
| 3 | 39 | 21·7 | 86·5 | 0·0129 | 0·0101 | 3·072 | 3·089 | 0·364 | 39·6 | 108·9 | 53·80 |
| 4 | 39 | 21·7 | 86·5 | 0·0129 | 0·0101 | 3·073 | 3·092 | 0·364 | 38·6 | 106·0 | 52·59 |
| 5 | ... | ... | ... | ... | Test strip damaged | | | ... | ... | ... | ... |
| 6 | 103 | 19·5 | 86·6 | 0·0123 | 0·0099 | 3·057 | 3·065 | 0·334 | 32·6 | 97·7 | 38·75 |
| 7 | 206 | 19·4 | 86·8 | 0·0124 | 0·0100 | 3·054 | 3·060 | 0·333 | 26·3 | 79·0 | 42·29 |
| 8 | 209 | 18·0 | 86·6 | 0·0122 | 0·0100 | 3·053 | 3·060 | 0·318 | 26·3 | 82·8 | 47·06 |
| 9 | 298 | 21·1 | 86·7 | 0·0128 | 0·0101 | 3·068 | 3·075 | 0·356 | 29·3 | 82·3 | 57·97 |
| 10 | 296 | 20·9 | 86·6 | 0·0129 | 0·0102 | 3·062 | 3·069 | 0·356 | 29·8 | 83·8 | 59·67 |
| | | (v) *20% 10th Passes* | | | | | | | | | |
| 1 | 12·9 | 19·4 | 89·9 | 0·0103 | 0·0083 | 3·070 | 3·087 | 0·304 | 56·2 | 185·0 | 63·17 |
| 2 | 12·9 | 19·6 | 89·4 | 0·0102 | 0·0082 | 3·070 | 3·091 | 0·305 | 56·7 | 186·0 | 64·78 |
| 3 | 41 | 19·8 | 89·2 | 0·0101 | 0·0081 | 3·089 | 3·109 | 0·306 | 46·7 | 152·8 | 64·30 |
| 4 | 41 | 19·8 | 89·2 | 0·0101 | 0·0081 | 3·092 | 3·106 | 0·306 | 48·2 | 157·7 | 62·56 |
| 5 | ... | ... | ... | ... | Test strip damaged | | | ... | ... | ... | ... |
| 6 | 101 | 22·2 | 89·5 | 0·0099 | 0·0077 | 3·065 | 3·082 | 0·320 | 47·0 | 147·0 | 49·45 |
| 7 | 208 | 19·0 | 89·4 | 0·0100 | 0·0081 | 3·060 | 3·072 | 0·297 | 28·3 | 95·3 | 46·95 |
| 8 | 210 | 19·0 | 89·1 | 0·0100 | 0·0081 | 3·060 | 3·069 | 0·297 | 27·8 | 93·6 | 52·15 |
| 9 | 300 | 18·8 | 89·3 | 0·0101 | 0·0082 | 3·075 | 3·085 | 0·298 | 31·9 | 107 | 64·25 |
| 10 | 300 | 19·6 | 89·3 | 0·0102 | 0·0082 | 3·069 | 3·085 | 0·305 | 32·3 | 106 | 63·54 |

TABLE VI (*b*)—*Results of Cold Rolling Tests on 3 × 0·075-in. High-Conductivity Copper Strip, at Various Speeds and Passes*

*Using a 10 × 10-in. Mill and A 40 Rolling Oil—1st, 2nd and 5th Passes of 30% Reduction; 6th Passes of 30% Reduction, and 1st Passes of 40% Reduction*

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Strip No. | Speed, ft./min. | Reduction in Pass, % | Reduction Overall, % | Thickness before Pass, in. | Thickness after Pass, in. | Width before Pass, in. | Width after Pass, in. | Contact Area, sq. in. | Total Roll Force, tons | Mean Roll Pressure, tons/sq. in. | Total Energy, h.p.hr./ton |
| | | | | (vi) *30% 1st Passes* | | | | | | | |
| 1 | 11·6 | 30·5 | 30·5 | 0·0773 | 0·0537 | 2·996 | 3·012 | 1·027 | 27·8 | 27·1 | 5·6 |
| 2 | 12·5 | 30·2 | 30·2 | 0·0771 | 0·0538 | 2·995 | 3·010 | 1·018 | 27·8 | 27·3 | 5·4 |
| 3 | 40 | 29·6 | 29·6 | 0·0759 | 0·0534 | 3·031 | 3·034 | 1·012 | 29·4 | 29·0 | 5·42 |
| 4 | 40 | 29·5 | 29·5 | 0·0753 | 0·0531 | 3·027 | 3·033 | 1·005 | 28·9 | 28·8 | 5·47 |
| 5 | 101 | 30·3 | 30·3 | 0·0749 | 0·0522 | 2·992 | 3·010 | 1·005 | 28·4 | 28·3 | 5·05 |
| 6 | 100 | 30·6 | 30·6 | 0·0759 | 0·0527 | 2·991 | 3·009 | 1·014 | 28·4 | 28·0 | 4·63 |
| 7 | 201 | 31·1 | 31·1 | 0·0762 | 0·0525 | 3·006 | 3·030 | 1·032 | 30·8 | 29·9 | 5·35 |
| 8 | 203 | 31·3 | 31·3 | 0·0761 | 0·0523 | 3·003 | 3·024 | 1·033 | 30·3 | 29·3 | 5·09 |
| 9 | 294 | 30·0 | 30·0 | 0·0758 | 0·0531 | 3·003 | 3·022 | 1·010 | 29·1 | 28·8 | 4·66 |
| 10 | 295 | 30·0 | 30·0 | 0·0761 | 0·0533 | 3·002 | 3·022 | 1·012 | 29·1 | 28·8 | 5·19 |
| | | | | (vii) *30% 2nd Passes* | | | | | | | |
| 1 | 11·2 | 30·9 | 52·0 | 0·0537 | 0·0371 | 3·012 | 3·022 | 0·861 | 35·9 | 41·7 | 14·7 |
| 2 | 11·7 | 30·5 | 51·5 | 0·0538 | 0·0374 | 3·010 | 3·025 | 0·856 | 35·9 | 41·9 | 14·4 |
| 3 | 40 | 29·6 | 50·4 | 0·0534 | 0·0376 | 3·034 | 3·043 | 0·848 | 34·9 | 41·2 | 13·76 |
| 4 | 40 | 29·6 | 50·3 | 0·0531 | 0·0374 | 3·033 | 3·040 | 0·844 | 35·4 | 42·0 | 13·62 |
| 5 | 100 | 32·2 | 52·7 | 0·0522 | 0·0354 | 3·010 | 3·022 | 0·868 | 34·7 | 40·0 | 12·80 |
| 6 | 100 | 32·8 | 53·4 | 0·0527 | 0·0354 | 3·009 | 3·021 | 0·880 | 34·2 | 38·9 | 12·86 |
| 7 | 195 | 28·8 | 51·0 | 0·0525 | 0·0374 | 3·030 | 3·040 | 0·828 | 33·7 | 40·7 | 11·77 |
| 8 | 194 | 28·7 | 51·0 | 0·0523 | 0·0373 | 3·024 | 3·037 | 0·824 | 33·7 | 40·9 | 11·68 |
| 9 | 290 | 30·7 | 51·5 | 0·0531 | 0·0368 | 3·022 | 3·037 | 0·860 | 36·0 | 41·8 | 13·06 |
| 10 | 288 | 30·8 | 51·5 | 0·0533 | 0·0369 | 3·022 | 3·040 | 0·864 | 36·0 | 41·7 | 16·99 |
| | | | | (viii) *30% 5th Passes* | | | | | | | |
| 1 | 12·7 | 29·2 | 83·0 | 0·0185 | 0·0131 | 3·040 | 3·058 | 0·497 | 44·6 | 89·8 | 50·0 |
| 2 | 12·9 | 28·8 | 82·5 | 0·0188 | 0·0134 | 3·041 | 3·058 | 0·497 | 44·6 | 89·8 | 51·3 |
| 3 | 40 | 23·2 | 82·5 | 0·0173 | 0·0133 | 3·068 | 3·079 | 0·434 | 35·4 | 81·5 | 46·0 |
| 4 | 40 | 25·7 | 82·7 | 0·0175 | 0·0130 | 3·059 | 3·065 | 0·456 | 34·9 | 76·5 | 44·81 |
| 5 | 102 | 30·8 | 83·1 | 0·0182 | 0·0126 | 3·041 | 3·060 | 0·506 | 35·7 | 70·6 | 39·87 |
| 6 | 101 | 30·6 | 83·5 | 0·0180 | 0·0125 | 3·042 | 3·056 | 0·504 | 35·2 | 69·9 | 41·18 |
| 7 | 203 | 31·1 | 83·5 | 0·0183 | 0·0126 | 3·058 | 3·070 | 0·515 | 35·7 | 69·3 | 39·49 |
| 8 | 203 | 31·7 | 83·6 | 0·0183 | 0·0125 | 3·056 | 3·069 | 0·518 | 35·2 | 66·8 | 40·75 |
| 9 | 294 | 30·2 | 83·2 | 0·0182 | 0·0127 | 3·059 | 3·067 | 0·506 | 33·0 | 65·2 | 62·86 |
| 10 | 295 | 29·5 | 83·3 | 0·0180 | 0·0127 | 3·059 | 3·070 | 0·496 | 33·0 | 66·5 | 59·59 |
| | | | | (ix) *30% 6th Passes* | | | | | | | |
| 1 | 12·8 | 29·0 | 88·0 | 0·0131 | 0·0093 | 3·058 | 3·087 | 0·421 | 68·2 | 162·0 | 72·0 |
| 2 | 12·2 | 31·4 | 88·0 | 0·0134 | 0·0092 | 3·058 | 3·087 | 0·442 | 69·2 | 156·5 | 74·7 |
| 3 | 40 | 32·4 | 88·2 | 0·0133 | 0·0090 | 3·079 | 3·109 | 0·452 | 63·2 | 140·0 | 67·3 |
| 4 | 40 | 30·8 | 88·0 | 0·0130 | 0·0090 | 3·065 | 3·095 | 0·434 | 64·2 | 148·0 | 66·01 |
| 5 | 103 | 30·2 | 88·4 | 0·0126 | 0·0088 | 3·060 | 3·078 | 0·420 | 46·0 | 109·5 | 52·62 |
| 6 | 105 | 30·4 | 88·6 | 0·0125 | 0·0087 | 3·056 | 3·076 | 0·420 | 46·5 | 110·7 | 55·90 |
| 7 | 205 | 29·4 | 88·4 | 0·0126 | 0·0089 | 3·070 | 3·084 | 0·416 | 39·6 | 95·2 | 51·75 |
| 8 | 206 | 28·0 | 88·2 | 0·0125 | 0·0090 | 3·069 | 3·083 | 0·406 | 39·7 | 97·8 | 54·85 |
| 9 | 295 | 29·9 | 88·2 | 0·0127 | 0·0089 | 3·067 | 3·085 | 0·421 | 37·1 | 88·1 | 82·76 |
| 10 | 292 | 29·9 | 86·2 | 0·0127 | 0·0089 | 3·070 | 3·083 | 0·421 | 38·1 | 90·5 | 77·59 |
| | | | | (x) 40% *1st Passes* | | | | | | | |
| 1 | 10·9 | 40·2 | 40·2 | 0·0774 | 0·0463 | 3·003 | 3·027 | 1·180 | 32·8 | 27·8 | 9·44 |
| 2 | 10·8 | 40·1 | 40·1 | 0·0768 | 0·0460 | 3·005 | 3·025 | 1·176 | 32·8 | 27·9 | 9·29 |
| 3 | 40 | 38·8 | 38·8 | 0·0751 | 0·0460 | 3·034 | 3·041 | 1·150 | 33·3 | 29·0 | 8·35 |
| 4 | 40 | 40·0 | 40·0 | 0·0767 | 0·0460 | 3·032 | 3·041 | 1·184 | 33·9 | 28·6 | 9·03 |
| 5 | 101 | 39·6 | 39·6 | 0·0754 | 0·0456 | 2·995 | 3·019 | 1·156 | 33·7 | 29·2 | 8·34 |
| 6 | 101 | 40·0 | 40·0 | 0·0760 | 0·0456 | 2·994 | 3·019 | 1·168 | 33·3 | 28·6 | 8·58 |
| 7 | 203 | 39·6 | 39·6 | 0·0758 | 0·0458 | 3·003 | 3·030 | 1·161 | 32·7 | 28·2 | 7·2 |
| 8 | 205 | 39·3 | 39·3 | 0·0743 | 0·0451 | 3·004 | 3·030 | 1·146 | 31·8 | 27·8 | 8·4 |
| 9 | 288 | 39·9 | 39·9 | 0·0764 | 0·0459 | 3·000 | 3·030 | 1·170 | 33·9 | 29·0 | 8·12 |
| 10 | 291 | 39·7 | 39·7 | 0·0758 | 0·0457 | 3·006 | 3·034 | 1·162 | 34·4 | 29·6 | 8·04 |

TABLE VI (*c*)—*Results of Cold Rolling Tests on 3 × 0·075-in. High-Conductivity Copper Strip, at Various Speeds and Passes*

*Using a 10 × 10-in. Mill, and A 40 Rolling Oil—3rd and 4th Passes of 40% Reduction; 1st and 2nd Passes of 60% Reduction; and 1st Passes of 90% Reduction*

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | (xi) *40% 3rd Passes* | | | | | | | |
| 1 | 11·1 | 41·7 | 79·4 | 0·0273 | 0·0159 | 3·044 | 3·068 | 0·727 | 51·6 | 71·0 | 49·68 |
| 2 | 11·1 | 39·7 | 78·7 | 0·0272 | 0·0164 | 3·044 | 3·067 | 0·706 | 53·1 | 75·1 | 47·85 |
| 3 | 40 | 41·3 | 78·8 | 0·0271 | 0·0159 | 3·054 | 3·076 | 0·726 | 46·2 | 63·7 | 42·14 |
| 4 | 40 | 40·4 | 78·5 | 0·0277 | 0·0165 | 3·052 | 3·075 | 0·726 | 46·7 | 64·4 | 41·88 |
| 5 | 101 | 39·8 | 78·4 | 0·0271 | 0·0163 | 3·036 | 3·051 | 0·704 | 42·1 | 59·8 | 39·49 |
| 6 | 101 | 40·4 | 78·6 | 0·0272 | 0·0162 | 3·032 | 3·049 | 0·710 | 43·6 | 61·4 | 38·55 |
| 7 | 204 | 40·3 | 78·5 | 0·0273 | 0·0163 | 3·053 | 3·066 | 0·713 | 36·7 | 51·5 | 34·4 |
| 8 | 205 | 39·8 | 78·2 | 0·0269 | 0·0162 | 3·047 | 3·061 | 0·702 | 37·2 | 53·0 | 34·9 |
| 9 | 289 | 39·8 | 78·4 | 0·0274 | 0·0165 | 3·051 | 3·068 | 0·710 | 35·4 | 49·8 | 35·72 |
| 10 | 293 | 40·6 | 78·4 | 0·0276 | 0·0164 | 3·051 | 3·068 | 0·720 | 35·9 | 49·8 | 35·54 |
| | | | | (xii) *40% 4th Passes* | | | | | | | |
| 1 | 11·8 | 37·7 | 87·2 | 0·0159 | 0·0099 | 3·068 | 3·105 | 0·531 | 75·0 | 141·3 | 76·6 |
| 2 | 11·8 | 38·4 | 86·9 | 0·0164 | 0·0101 | 3·067 | 3·102 | 0·543 | 75·1 | 138·3 | 74·1 |
| 3 | 40 | 37·2 | 86·7 | 0·0159 | 0·0100 | 3·076 | 3·100 | 0·528 | 60·8 | 115·2 | 65·7 |
| 4 | 40 | 39·4 | 86·9 | 0·0165 | 0·0100 | 3·075 | 3·105 | 0·553 | 60·7 | 109·9 | 67·2 |
| 5 | 101 | 41·1 | 87·3 | 0·0163 | 0·0096 | 3·051 | 3·072 | 0·557 | 49·0 | 87·9 | 59·9 |
| 6 | 103 | 39·5 | 87·1 | 0·0162 | 0·0098 | 3·049 | 3·069 | 0·545 | 49·0 | 89·9 | 56·8 |
| 7 | 205 | 38·0 | 86·7 | 0·0163 | 0·0101 | 3·066 | 3·085 | 0·538 | 39·6 | 73·6 | 51·0 |
| 8 | 205 | 39·5 | 86·8 | 0·0162 | 0·0098 | 3·061 | 3·080 | 0·546 | 37·7 | 69·0 | 52·6 |
| 9 | 297 | 40·6 | 87·2 | 0·0165 | 0·0098 | 3·068 | 3·087 | 0·560 | 39·0 | 69·7 | 58·6 |
| 10 | 295 | 40·2 | 87·2 | 0·0164 | 0·0098 | 3·068 | 3·089 | 0·556 | 38·4 | 69·1 | 51·8 |
| | | | | (xiii) *60% 1st Passes* | | | | | | | |
| 1 | 11·0 | 60·2 | 60·2 | 0·0780 | 0·0311 | 3·000 | 3·037 | 1·454 | 45·1 | 31·0 | 23·6 |
| 2 | 11·5 | 60·6 | 60·6 | 0·0761 | 0·0300 | 2·999 | 3·036 | 1·439 | 45·1 | 31·3 | 23·8 |
| 3 | 41 | 59·1 | 59·1 | 0·0766 | 0·0313 | 2·995 | 3·028 | 1·425 | 41·2 | 28·9 | 18·7 |
| 4 | 41 | 58·3 | 58·3 | 0·0751 | 0·0313 | 2·995 | 3·031 | 1·400 | 40·2 | 28·7 | 18·6 |
| 5 | 95 | 60·8 | 60·8 | 0·0764 | 0·0300 | 2·993 | 3·036 | 1·440 | 45·6 | 31·7 | 19·6 |
| 6 | 95 | 60·1 | 60·1 | 0·0761 | 0·0303 | 2·994 | 3·033 | 1·432 | 42·1 | 29·4 | 20·2 |
| 7 | 196 | 61·5 | 61·5 | 0·0764 | 0·0294 | 3·005 | 3·041 | 1·46 | 37·7 | 25·8 | 19·6 |
| 8 | 195 | 60·9 | 60·9 | 0·0752 | 0·0294 | 3·003 | 3·041 | 1·44 | 38·1 | 26·5 | 19·1 |
| 9 | 274 | 59·7 | 59·7 | 0·0787 | 0·0317 | 3·005 | 3·050 | 1·461 | 37·7 | 25·8 | 18·3 |
| 10 | 274 | 60·1 | 60·1 | 0·0784 | 0·0313 | 3·004 | 3·045 | 1·460 | 38·3 | 26·2 | 20·4 |
| | | | | (xiv) *60% 2nd Passes* | | | | | | | |
| 1 | 7·0 | 60·8 | 84·4 | 0·0311 | 0·0122 | 3·037 | 3·102 | 0·939 | 95·5 | 101·8 | 82·0 |
| 2 | 7·5 | 57·7 | 83·2 | 0·0300 | 0·0127 | 3·036 | 3·102 | 0·896 | 96·9 | 108·3 | 79·5 |
| 3 | 48 | 64·8 | 85·6 | 0·0313 | 0·0110 | 3·028 | 3·075 | 0·967 | 59·4 | 61·4 | 60·5 |
| 4 | 40 | 59·4 | 83·1 | 0·0313 | 0·0127 | 3·031 | 3·071 | 0·924 | 62·8 | 68·0 | 56·1 |
| 5 | 101 | 59·0 | 84·0 | 0·0300 | 0·0123 | 3·036 | 3·067 | 0·904 | 55·4 | 61·2 | 52·6 |
| 6 | 103 | 64·0 | 85·7 | 0·0303 | 0·0109 | 3·033 | 3·066 | 0·942 | 53·4 | 56·6 | 52·8 |
| 7 | 195 | 65·6 | 86·8 | 0·0294 | 0·0101 | 3·041 | 3·065 | 0·940 | 44·1 | 47·0 | 53·9 |
| 8 | 196 | 66·3 | 86·8 | 0·0294 | 0·0099 | 3·041 | 3·066 | 0·950 | 42·1 | 44·4 | 53·5 |
| 9 | 284 | 65·3 | 86·1 | 0·0317 | 0·0110 | 3·050 | 3·072 | 0·980 | 37·2 | 38·0 | 46·1 |
| 10 | 280 | 58·1 | 83·3 | 0·0313 | 0·0131 | 3·045 | 3·076 | 0·918 | 41·7 | 45·5 | 47·3 |
| | | | | (xv) *90% 1st Passes* | | | | | | | |
| 1 | 10·0 | 90·2 | 90·2 | 0·0798 | 0·0079 | 3·002 | 3·109 | 1·822 | 86·3 | 47·3 | 165·0 |
| 2 | 10·0 | 90·7 | 90·7 | 0·0807 | 0·0075 | 3·008 | 3·111 | 1·842 | 88·7 | 48·2 | 171·0 |
| 3 | 40 | 88·8 | 88·8 | 0·0753 | 0·0084 | 3·027 | 3·095 | 1·760 | 73·0 | 41·5 | 129·3 |
| 4 | 39 | 88·3 | 88·3 | 0·0768 | 0·0090 | 3·021 | 3·100 | 1·771 | 74·9 | 42·2 | 123·7 |
| 5 | 101 | 85·9 | 85·9 | 0·0790 | 0·0111 | 2·991 | 3·104 | 1·764 | 74·4 | 42·1 | 97·4 |
| 6 | 101 | 85·4 | 85·4 | 0·0800 | 0·0117 | 2·991 | 3·105 | 1·772 | 78·9 | 44·5 | 93·9 |
| 7 | 184 | 88·3 | 88·3 | 0·0762 | 0·0089 | 2·996 | 3·059 | 1·750 | 48·0 | 27·5 | 96·2 |
| 8 | 184 | 88·4 | 88·4 | 0·0748 | 0·0087 | 2·995 | 3·059 | 1·730 | 48·5 | 28·0 | 89·2 |
| 9 | 275 | 90·0 | 90·0 | 0·0758 | 0·0076 | 2·997 | 3·077 | 1·763 | 45·0 | 25·5 | 102·0 |
| 10 | 269 | 89·9 | 89·9 | 0·0753 | 0·0076 | 2·997 | 3·084 | 1·759 | 49·0 | 27·9 | 107·3 |

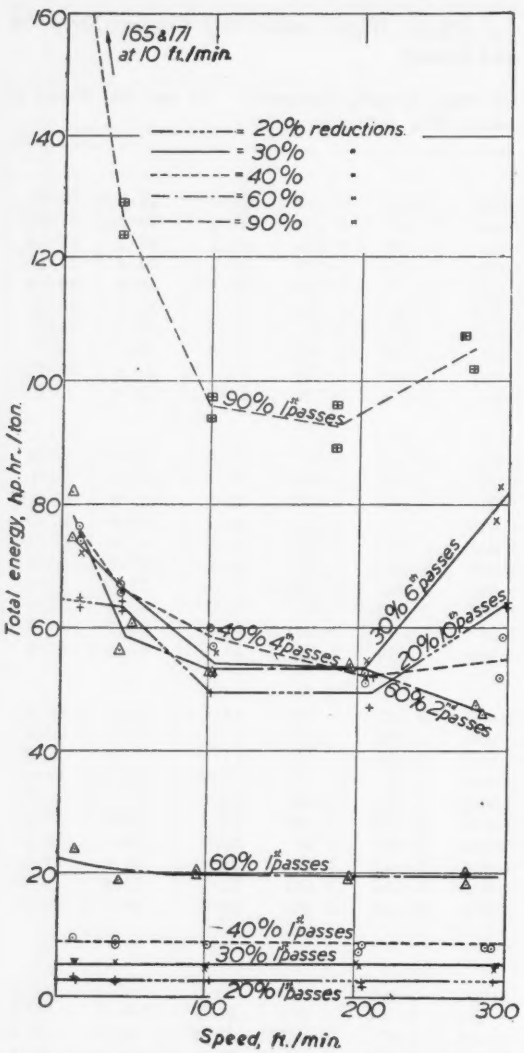


FIG. 11—Variation of total energy with speed ; H.C. copper, 0·075-in. strip

## REVIEW OF THE RESULTS

The following conclusions are drawn from the tests just described :

1. The tests confirm the findings of previous researches, in that the pressure required for rolling a first pass of normal reduction (up to 60%) on annealed material is independent of the speed of rolling. The roll torque and energy consumption are also independent of speed.

2. After work-hardening has taken place and the strip has become thin, the roll pressure begins to be dependent on speed to a marked degree over the range 5 to 300 ft./min. There is insufficient data at the moment to be able to relate this phenomenon to any particular value of percentage deformation, to the absolute thickness of the material, or to the ratio :

$$\frac{\text{Diameter of the roll}}{\text{Thickness of strip}}.$$

With rolls of diameter larger than 10 in., the phenomenon will probably appear at an earlier point than that stated above. On the other hand, if the rolls are smaller than 10 in. dia., there will be no sizable effect until the strip is somewhat thinner.

It is worth noting that with the copper strip the speed effect becomes noticeable at the following stage :

(*a*) 0·05-in. strip : at the third pass of 30%, *i.e.*, 65·7% total reduction—0·0171 in. residual thickness.

(*b*) 0·075-in. strip : between the third and fourth passes (nearer to the fourth pass) of 30%, *i.e.*, 76·0% total reduction—0·018 in. residual thickness.

(*c*) 0·10-in. strip : at the fifth pass of 30%, *i.e.*, 83·2% total reduction—0·0168 in. residual thickness.

It would appear that for a material which does not work-harden very rapidly, irrespective

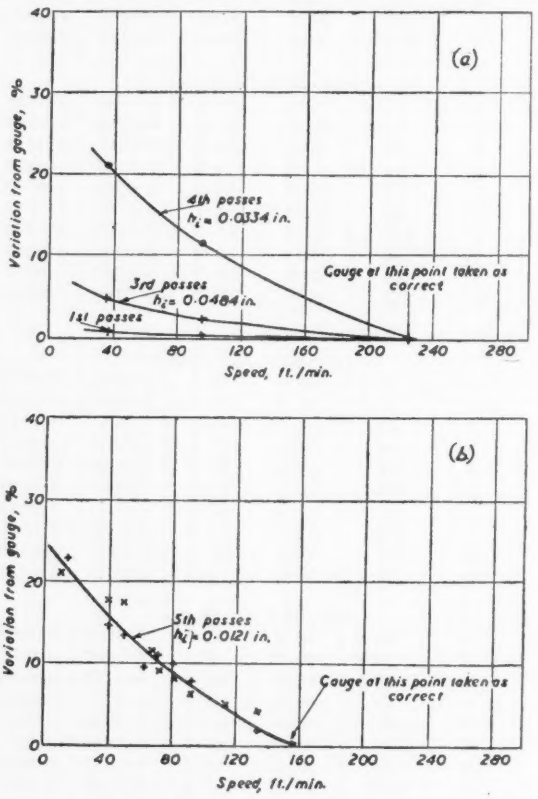


FIG. 12—Effect of speed on strip gauge. Strip initially 3 × 0·1 in., rolls set for 30% reduction and not changed with speed

(*a*) 0·2%-C steel (*see* Table I)

(*b*) H.C. copper strip (*see* Table VIII)

of total reduction, the effect is found when the strip becomes about 0·017 in. thick.

With the 0·2%-C steel strip, the effect is noticeable at the third pass—66%, *i.e.*, a thickness of 0·034 in.

With the 0·032-in. strip the effect is well marked at the second pass—51%, *i.e.*, a thickness of 0·016 in.

Except, therefore, for the hard steel, the thickness is generally around 0·017 in. It is probable that the effect will appear at geometrically similar points in mills having larger or smaller rolls than 10 in., *i.e.*, for a diameter/thickness ratio of $10/0{\cdot}017 = 590$. At pass reductions smaller than 30% the critical thickness is smaller (*i.e.*, diameter/thickness ratio greater), and conversely for larger pass reductions.

3. The factors mentioned under conclusion 2 are those which chiefly govern excessive roll flattening and decide the minimum thickness which can be rolled.

4. Allowance must be made for these tendencies in assessing the results obtained in cold-rolling experiments where the material is very thin or strongly work-hardened, and particularly in comparing 'spot' readings taken on industrial plant.

5. The effects so far observed may be of some importance in commercial rolling when the strip is thin ; that is, roughly where material has been reduced about 70% from the normal thicknesses at which cold-rolling begins. The effect of speed will certainly appear when rolling tinplate gauges for example, and in thin strip intended for such purposes as razor blades.

6. The speed range covered in these experiments is not large and it is possible that the roll force will drop even further with higher speeds, although there are signs that it is decreasing at a slower rate when approaching 300 ft./min.

7. The energy consumption under the same conditions of rolling appears to depend to a lesser extent on speed than does roll pressure, and in a rather more complex fashion. The energy per ton of material passing through the roll gap is definitely greater at low speeds than at intermediate speeds, but usually appears to rise again at the highest speeds reached in these tests. This applies to those conditions where the speed affects roll pressure. In the first passes up to 60%, the energy consumption, as with roll pressure, is essentially unaffected by speed of rolling.

8. The results also mean that it is possible to roll thinner at high speeds than at low speeds.

## General Discussion of the Results

There are several possibilities as to the cause of this effect and these will now be considered :

(*a*) *Dependence of Yield Stress on Rate of Deformation*—The discussion of previous researches indicates that the yield stress does not change appreciably with rate of deformation, any effect (*e.g.*, for copper) which has been observed being to increase the yield stress with increase of speed. In the rolling tests the roll force shows a considerable decrease in value as the speed increases, not an increase, as would be required by a higher yield stress. The rate of deformation in the tests described in the foregoing was never more than 275 sec.$^{-1}$, as compared with rates of up to about 1000 sec.$^{-1}$ in the impact tensile tests referred to. This possibility can be ruled out.

(*b*) *Effect of Temperature Rise Resulting from the Work Done in Deforming the Material*—The energy consumed in deforming the material mainly appears as heat. Taylor and Quinney have shown[11] that when a metal is subjected to cold working, most of the work done re-appears as heat, although a proportion remains latent in the metal.

For annealed mild steel they show that the latent energy varies from about 11% to 7% of the work done by progressive distortion by twisting. They also tested pure annealed copper, and found that over a wide range of distortion the latent energy averaged 8–9% of the work done, but when the copper had been worked very considerably (corresponding to a compressive strain of about 80%) the metal reaches a state in which it is saturated with latent energy and all the work done in causing further deformation appears entirely as heat.

As the latent energy is only a small proportion of the deformation energy, therefore, it will be ignored in what follows.

In cold rolling, the energy consumed is made up of two main constituents, *viz.*, the work done in deforming the material approximately in homogeneous compression (given by the expression $\int_{h_0}^{h} k \cdot \frac{dh}{h}$, where $k$ = yield stress), and the frictional work arising from the sliding of the surface of the strip over the roll as it passes through the roll gap.

We can calculate the effective temperature rise which would be found assuming that all the energy consumed in the process appears as heat in the strip. In actual fact, the strip will lose heat to the rolls and a certain amount by conduction back into that part of the strip which has not yet reached the roll gap ; but this will lower the temperature, and the above assumption will therefore yield the maximum temperature rise.

Taking typical passes from the Tables :

(i) 0·05-in. copper, 4th and 5th passes—

Energy consumed in 4th pass
= 16·8 h.p.hr./ton (average for all speeds)
= 10·7 cal./g.
Energy consumed in 5th pass
= 24·0 h.p.hr./ton (average for all speeds)
= 15·2 cal./g.
Taking the specific heat of copper as 0·0923,
Temperature rise in 4th pass = 118° C.
,, ,, ,, 5th ,, = 164° C.

(ii) 0·075-in. copper, 90% single pass—
Energy consumed = 64 cal./g.
Temperature rise = 690° C.

(iii) 0·10-in. copper, 6th pass of 30%—
Energy consumed = 11·4 cal./g.
Temperature rise = 123° C.

(iv) 0·10-in. 0·2%-C steel, 4th pass of 30%—
Energy consumption = 18·5 cal./g. (average)
Taking the specific heat of steel as 0·106
Temperature rise = 174° C.

The amount of heat lost to the rolls is difficult to determine, because the heat flow involves an unknown heat transfer coefficient between the strip and roll surfaces, and an unsteady heat flow with time into the roll. The heat lost depends on the time interval that the roll and strip are in contact, and on the temperature ; the heat developed in that time is proportional to the speed of rolling. Hence the heat loss will be a greater fraction of the heat developed at a low speed than at a high speed, and the strip temperature will accordingly be higher at a high speed of rolling than at a low speed of rolling.

It is possible, therefore, that these differences of temperature are such that at a high speed the yield stress characteristic—which depends on temperature—would be reduced, resulting in a lower roll force.

A number of possible heat-transfer coefficients between strip and roll were taken and the heat balance determined. For example, in the fifth pass at a reduction of 30% on strip initially 0·05 in. thick.

Temperature rise (average) assuming no heat loss to the roll = 164° C.
With a heat-transfer coefficient of 0·0136 (cal./sq. cm./°C./sec.),
Temperature rise at 7 ft./min. = 130° C.
Temperature rise at 204 ft./min. = 164° C.
If the heat transfer is better than this, say 0·1 cal./sq./cm./° C. sec.
Then temperature rise at 7 ft./min. = 56° C.
,, ,, ,, ,, 204 ft./min. = 154° C.

It is clear that if the heat transfer is reasonably good the difference in speed could make large differences in the temperatures reached. If these differences exist, the next question which arises is whether the temperature rises high enough to cause a drop in the yield stress characteristics.

Most of the evidence at present available[12,13,14,15] only refers to the effect of temperature (over the range 0°–500° C.) on the yield point and ultimate stress of annealed materials. Most annealed low carbon steels show[12, 15] no falling-off in ultimate stress up to 250° C. and then in most cases a ' hump ' appears, and this may continue to about 350° C. before falling fairly rapidly at higher temperatures. The yield point shows some reduction for a 0·2%-C steel over a temperature range of 230° C.,[14] but Tapsell[13] says, "up to approximately 250° C. the yield point is well defined and its value is not much changed ; beyond 300° C., however, no definite yield point exists."

It should be borne in mind that these results relate to heat-treated steels and not to strongly work-hardened steels. Only Manjoine and Nadai[16, 17] show actual stress/strain curves for copper and mild steel where work-hardening occurred with progressive deformation in tension.

Majoine and Nadai tested mild steel and pure copper at various rates of deformation and at various temperatures. The results show a progressive reduction in the stress with rise in temperature at any given strain both with steel and copper.

The results for copper, taken from the figures in the references,[16,17] are given in Table VII for a rate of deformation of 135 sec.$^{-1}$. This rate should be representative of that of the present tests.

These figures show a rise in yield stress of 10 to 13% with increase of the rate of deformation (columns *a* and *b*) from 0 to 135 sec.$^{-1}$. At this speed, the temperature must be as high as 200° C. before the yield stress has dropped to the value for the static test at atmospheric temperature. Even at 400° C., the yield stress has only dropped about 15–20% below the static condition. Yet the reduction in roll force found in the rolling tests is of the order of 40% or even more, in cases (*e.g.*, *see* Fig. 8) where the maximum temperature

TABLE VII—*Stress/Strain Data for Pure Copper Strained at Various Speeds and Temperatures (after Manjoine and Nadai)*

| Elongation, % | (*a*) Stress for Static Test at Room Temperature, tons/sq. in. | Stress for Straining Rate of 135 sec.$^{-1}$ at Various Temperatures, tons/sq. in. | | | |
|---|---|---|---|---|---|
| | | (*b*) Atmospheric Temp. | (*c*) 200° C. | (*d*) 400° C. | (*e*) 600° C. |
| 5 | 7·6 | 11·0 | 8·5 | 8·4 | 6·0 |
| 10 | 10·6 | 13·4 | 11·2 | 9·8 | 7·1 |
| 15 | 12·1 | 14·5 | 12·1 | 10·5 | 7·8 |
| 20 | 13·4 | 15·2 | 13·0 | 11·0 | 7·8 |
| 25 | 14·0 | 15·5 | 13·2 | 11·2 | 8·5 |
| 30 | 14·1 | 15·9 | 13·4 | 10·9 | 8·5 |
| 35 | 14·0 | 15·6 | 13·2 | 10·3 | 7·5 |
| 40 | 13·4 | 14·1 | 12·5 | 8·9 | 7·2 |

difference could not be more than 160° C. (*see* example (i) on page 396).

The results given by Manjoine and Nadai[17] for a mild steel tested in the same way show no reduction in ultimate stress as between the static test at atmospheric temperature and tests at strain rates of 200 sec.$^{-1}$ for temperatures of 200° and 400° C. Coupled with the evidence already quoted (on page 396) it would therefore seem that over the range 0 to 300° C. there appears no tendency for the yield stress to drop under the rolling conditions for steel represented in these tests. Yet the roll force was found to drop 30% with the 0·2%-C steel and over 40% with the thin, low carbon steel strip.

While further experimental evidence is needed to show the effect of temperature on the yield tress of work-hardened materials, it would seem that temperature effects cannot be the cause of the phenomenon found in rolling tests. If this were the explanation, the greatest drop in roll force would be expected where the greatest temperatures are theoretically obtainable, *i.e.*, the heavy reductions, where the greatest energy input values are found. But these heavy passes, while showing the effect, do not show it to any remarkably greater extent. The fact that steel shows no drop in strength with temperatures up to 250° C., would require that the roll force should not fall with speed if the temperature variation were the explanation, yet the roll force drops by about the same amount as in the copper rolling tests.

(*c*) *Effect of Roll Flattening*—There is considerable roll flattening in all those cases where the speed effect is found. If the shape of the arc of contact changed with speed of rolling, in such a way that the flattening of the roll decreased, or changed shape to such an extent as to concentrate the total deformation into a small portion of the actual flattened arc of contact, the same reduction could conceivably be made for a smaller roll force.

TABLE VIII—*Rolling Tests With and Without Lubricant*

| With Lubricant | | | | Without Lubricant | | |
|---|---|---|---|---|---|---|
| Speed, ft./min. | Pass No. | Pass Reduction, % | Mean Roll Pressure, tons/sq. in. | Speed, ft./min. | Pass Reduction, % | Mean Roll Pressure, tons/sq. in. |
| 10 | All | 23·6 | 138·2 | 14 | 25·6 | 137·5 |
| 40 | 5th | 25·6 | 133·0 | 40 | 27·8 | 131·7 |
| 50 | passes | 25·8 | 132·5 | 50 | 28·5 | 130·7 |
| 67 | of | 29·5 | 125·0 | 62 | 31·0 | 124·5 |
| 72 | initial | 31·2 | 120·7 | 71 | 30·4 | 126·7 |
| 81 | thick- | 31·7 | 123·0 | 81 | 30·7 | 126·5 |
| 92 | ness | 32·9 | 126·0 | 91 | 32·1 | 123·5 |
| 113 | of | 33·7 | 123·7 | 113 | 34·1 | 121·0 |
| 134 | 0·0121 | 34·3 | 123·8 | 134 | 35·8 | 122·0 |
| 154 | in. | 36·9 | 119·5 | 155 | 37·0 | 121·0 |

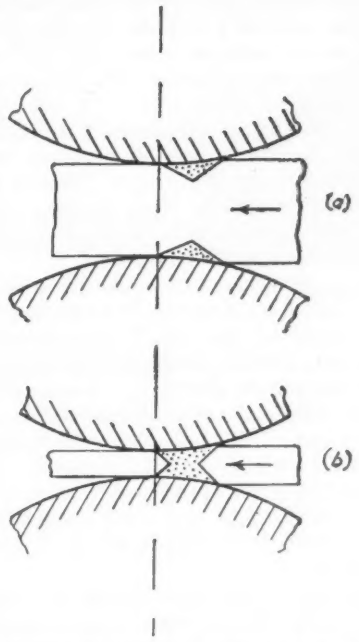


FIG. 13—Diagram to illustrate the effect of friction when rolling thin strip

It is difficult to conceive, however, what mechanism could cause this to happen, since the inertia of the roll to its own elastic deformation cannot be very great at the speeds obtaining in these experiments.

(*d*) *Variation of the Friction between Roll and Strip*—The S.K.F. researches suggested that more lubricant may be carried into the roll gap the higher the speed, and this would reduce the coefficient of friction. This appears the most likely explanation, since it is thought that the friction between the roll and the strip gives rise to wedges of unplastic material (*see* Fig. 13 (*a*)), and when the strip is very thin the two wedges from the opposite surfaces of the strip must meet and interfere (Fig. 13 (*b*)), causing a considerable increase in resistance to deformation. (It should be understood that the shape of the wedges shown in Fig. 13 is only diagrammatic.) A small change in the coefficient of friction could make an appreciable change in the angle subtended by the wedges, and allow the material to be rolled thinner before the wedges interfered.

To check this point a few tests were made on a number of strips of copper, initially 0·05 in. thick, rolled down to a uniform thickness of 0·0121 in. The rolls were set to give approximately 30% reduction at a speed of about 60 ft./min., and were not adjusted for each speed. The

first set of strips were rolled using Vacuum A 40 rolling oil copiously applied to rolls and strip, and the second set were rolled with rolls and strip carefully cleaned and dried. The results are given in Table VIII.

The differences in roll pressure are insignificant compared with the possible random variations when working with thin strips. The roll pressures in the two conditions drop in step with each other, and the reductions increase by the same amounts as the speed increases.

Drying off the rolls should have eliminated entirely the effect of speed, if the suggestion made in the report on the S.K.F. experiments is the correct one, since as the speed increases there is no lubricant to be drawn in. Even allowing for the fact that it is very difficult to remove from the strip surface all possible surface films which are likely to act as partial lubricants, there was certainly insufficient lubricant to form a wedge of lubricant in the gap, and there should have been some difference in the readings if the above explanation is correct.

While the experimental evidence requires confirmation by further tests over a wider speed range, it is thought that enough has been done to cast doubt on this explanation of the drop in roll pressure.

## Conclusion

Experimental evidence has been put forward which establishes, on a quantitative basis, the facts which have been frequently noted by rolling-mill engineers and operatives, that roll force and (to a lesser extent) roll torque are dependent on the speed of rolling, when the strip has been rolled fairly thin.

So far, no explanation has been found for this phenomenon, and it is hoped that the information given in this paper may stimulate interest, and lead to a suggestion as to the cause. The phenomenon undoubtedly contributes to ' off-gauge ' strip in wide-strip mills and other mills rolling thin-gauge material, during acceleration and deceleration, and is of importance from this point of view and, possibly, in the future development of the cold-rolling process.

## Acknowledgments

I wish to thank the Rolling Committee of the British Iron and Steel Research Association for permission to publish the results of this work. I also wish to thank my colleagues in the Mechanical Working Division for their help, and in particular Mr. John Rankine and Mr. C. N. Kington, M.B.E.

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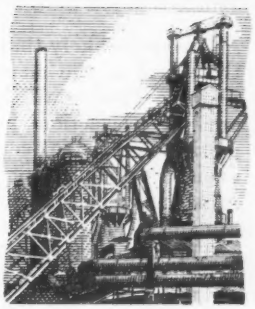
IRON AND STEELWORKS ENGINEERING

THE IRON AND STEEL ENGINEERS GROUP



# THE IRON AND STEEL ENGINEERS GROUP

## *REPORT OF THE THIRD MEETING*

THE THIRD MEETING OF THE IRON AND STEEL ENGINEERS GROUP of the Iron and Steel Institute was held at the Offices of the Institute, 4, Grosvenor Gardens, London, S.W. 1, on Wednesday, 26th February, 1947. Mr. W. F. CARTWRIGHT (Messrs. Guest Keen Baldwins Iron and Steel Co., Ltd.), Chairman of the Group, presided. Approximately 120 people attended the meeting.

AT THE MORNING SESSION papers on " The Blast-Furnace of Today " were introduced by Major W. R. Brown (" A Review of Current Furnace Engineering ") and Mr. I. S. Scott-Maxwell (" A Commentary on Current Furnace Engineering "). The discussion was opened by Mr. A. Bridge, who commented on furnace-plant layout.

AT THE AFTERNOON SESSION papers were introduced by Mr. T. H. Stayman (" Some Notes on Recent American Blast-Furnaces ") and Mr. D. C. Hendry (" Engineering Problems in the Preparation of Ores for Blast-Furnaces "). Mr. Bridge and the Chairman, respectively, opened the discussion on the two papers.

### PROCEEDINGS OF THE MORNING SESSION : 10.00 A.M. to 12.45 P.M.

The **Chairman:** I am very pleased to see what must be considered a relatively good attendance under the conditions which prevail. It is somewhat smaller than at the previous meetings, but in view of present circumstances it is a good one.

I should like first to welcome a number of members from France and Belgium who are here today. I hope that they will take part in the discussion of the papers.

We wish at these meetings to concentrate on one type of engineering at a time, so that we shall not have people coming to a meeting who are not really interested in what is going on. I think that the blast-furnace of today is very much an engineering subject, and it is growing more and more every day an electrical engineers' subject, so that I hope that we shall have some contributions from the electrical side as well as from the mechanical.

### Discussion on THE BLAST-FURNACE OF TODAY

### Pt. I—A Review of Current Furnace Engineering*

*by W. R. Brown*

Major **W. R. Brown** (Messrs. Ashmore, Benson, Pease & Co., Ltd.), introducing his paper, said: The present is a time of extreme significance to the blast-furnace men of this country. We are faced with a large rebuilding programme, and therefore we must summon together all our forces and try to carry out the task to the very best of our ability. Whether this rebuilding programme is a great success or a failure will, in any case, depend very largely on the people in this room. They and their confreres will, even if the major decisions are made at a higher level, be responsible for carrying them out, and I feel sure that each of us has some contribution to make to success.

* *Journal of the Iron and Steel Institute*, 1947, vol. 155, Jan., pp. 107–115.

It is quite likely that we shall not compete with the world in the magnitude of the new furnace plants. That is all the more incentive to us to aim at perfection in the engineering, giving meticulous care to every detail, so that our plants, even if they are not the largest, will certainly rank high for the unsurpassed thought and effort put into them.

The papers for which Mr. Scott-Maxwell and I are responsible are not intended to dogmatize. The intention was that I should prepare an outline of the level to which blast-furnace engineering had arrived in this country, and he would make some comment on present achievements and suggest future trends of development. It is ideas about future developments that we very much want brought out at this meeting.

I should like to dispel any idea which you may have that plant manufacturers are obdurate, or unresponsive to suggestion. We certainly are not so intentionally, but when many contradictory suggestions are proffered, obviously some must be disregarded.

I feel that Fig. 1 of the paper would have been more informative had we used the centre-line of the tuyeres as the common datum from which to start. The difference in the shape of the furnace hearths, as shown, makes the comparison rather deceptive.

In Fig. 3 (*b*) a dimension line at the bottom has not come out well in the reproduction. It is immaterial, but it should have gone across to the shear leg of the ore bridge and not finished half-way across.

In Fig. 4, at the left-hand side a rail track enters underneath the cast-house floor; this should proceed right across to emerge as the corresponding track at the right-hand side. The tracks whereon the hot metal ladles stand should continue as dotted lines under the floor until they emerge on the right-hand side.

Almost everything in the paper is a factual account of installations, either planned or in being, and therefore there is little that I can add now.

## Pt. II—A Commentary on Current Furnace Engineering*

### *by I. S. Scott-Maxwell*

Mr. **I. S. Scott-Maxwell** (British Iron and Steel Federation), introducing his paper, said : There is no doubt that we have a great deal of building to do in the future, and much of the success of these plants will be the responsibility of the engineers and designers. Taking a broad view, the economic aspect must be kept in mind when considering any new development, and the cost of operating the final plant is of paramount importance. Very often there is a tendency to save on the initial capital expenditure, and in later years we have to pay out money which would have been better spent at the start.

One of the major problems in the iron and steel industry is the handling of the large amounts of material involved. For the total pig-iron production of Great Britain as envisaged about ten years hence, there will be some 45,000,000 to 50,000,000 tons of material to be moved about the country in the shape of coal, ore, limestone, iron, and slag. We have from America modern handling plant and large-capacity dock unloaders and so on. Without going into the merits of these different pieces of equipment, I would say that, generally speaking, we are very often faced with weak links here and there. This is one of the most annoying features of plant operation. The machine itself is well designed for the job, but we are continually faced with intermittent breakdowns due to bad limit switches, a troublesome gear-box, or some weak shaft which brings everything to a standstill. I think that designers might pay more attention to the smaller details which may seem insignificant, but which nevertheless assure the continuity of the whole.

The problem of handling washer slurry on a blast-furnace plant is always difficult. As far as I know, present-day vacuum filters bring down the moisture to only 18–20%, and to handle wet flue dust or slurry of such moisture content is very difficult. Why cannot we have something better than that ? It might be done with a drying stage, as suggested in the paper, or with better filter equipment. There is no reason why breeze from the furnace screens, flue dust from the pug mills, and semi-dry washer slurry should not all be handled by conveyers to the sinter plant, thus eliminating internal works traffic.

Ore preparation is a vital factor in the success of any new plant. The problem for the foreign-ore plant using high-grade ores is somewhat different from that of the plant situated on home-ore fields. One of the main pieces of machinery in an ore-preparation plant is the crushing machine. With foreign ore, crushing does not present very much difficulty, because the ore is dry and generally free-running and of a somewhat stony nature, but the home ore is wet, clayey, and sticky. Primary crushers for home ore are reasonably satisfactory, but there have been no really good secondary crushers for the preparation of fine ore for sintering purposes, that is, crushing down to $\frac{3}{8}$ in.

Mr. Hendry, in the paper which is to be discussed this afternoon, has developed an idea for screening

* *Journal of the Iron and Steel Institute*, 1947, vol. 155, Jan., pp. 115–120.

Northamptonshire ore, which is also a difficult problem, but it seems to me that the manufacturers of crushing equipment have not investigated the problems involved in crushing wet material down to the small size desired. It may not be possible, of course ; it may be necessary to dry the material, but some investigation into the problems of crushing would be of benefit. Even on the foreign-ore plants, you want to crush in such a way that you produce the minimum amount of fines. Different crushers and varying types of ore produce different amounts of fines. Any proper investigation of the problem should involve the study of shear and compression on the types of ore and the different actions of the various crushers.

On the materials side, there is always the question of handling scrap into a blast-furnace. There will be certain types of scrap which will always be available for blast-furnaces, and there is no doubt that a certain proportion of scrap is beneficial as regards fuel consumption and tends to keep the inside of the furnace clean. We all had to use more scrap during the war, and it was generally put into the furnace by hand, in some makeshift way. Why cannot we have a proper set-up for charging prepared scrap to a blast-furnace ? It would not require much room or machinery. The difficult part would be to handle the prepared scrap from the scrap-yard to the skip, because it is no good dumping it in in irregular quantities ; to keep the hearth temperature and iron quality right you must charge scrap regularly.

To continue on the charging question, if we are agreed—and I think that most operators are—that a blast-furnace should be charged with properly prepared and sized material, then this point should be kept in mind when designing the ore-preparation plant. Two aspects arise, one for foreign ores and one for home ores, and each is different. (*The speaker then read an extract from his paper, from "Home ores vary considerably," in the first column of page* 117, *down to "stocking excess production," in the second column.*

In present-day layouts the stockyard is generally adjacent to and directly behind the high-line bunkers, but if you are going to make screening the last operation before charging to the furnace bunkers, you will see from the diagrams in the paper (which are very schematic) that there is a possible displacement of the stock-yard in relation to the high-line.

With regard to the charging equipment on the furnace itself, both Mr. Cartwright and Major Brown have mentioned electrical developments. There are many arguments for and against different types of electrical skip drive. The only criticism which I would make of Major Brown's picture of a charging-control panel (Fig. 9) is that it seems to me to be getting very complicated ; there are some 40 items, many of them push-buttons. The instruments which he shows are very good, and I do not think that they could be dispensed with, but I think that the number of push-buttons for all the different jobs is a little overdone.

In the development of an electrical piece of apparatus, the tendency is to add more and more different buttons and contacts and sequences until you get the thing so complicated that you wipe it all out and start all over again. That has happened time and again in other spheres of electrical development, and it seems to me that blast-furnace charging control is getting to the point where it should be simplified and not made more complicated.

One small point which I should like to mention is that of rope stretch on a blast-furnace skip. The skip tipping angle must be correctly maintained if you are not to upset your distribution inside the furnace. Particularly when you put on new ropes, but also over quite a long period, the skip ropes stretch and the skips come down. You have usually to put the furnace off to pull up the ropes or take up the adjustment on the screws at the skip. That takes time, and it means putting the furnace off blast for a certain period. Nothing is more annoying than having to put a furnace off wind, particularly if it is moving well. I think that it would be an advantage, therefore, if designers would think of some easier and more simple way of taking up rope stretch. I have suggested some form of split winch drum, because with a solid drum you cannot do it by manipulating the limit switches.

At the top of the furnace, the most widely used charging apparatus is the McKee top. My experience with the McKee top has been perfectly satisfactory, except that the small-bell hopper often seems to wear out before the small bell does, which does not seem to be a good arrangement ; the small-bell hopper should surely last the life of the small bell, while the large bell and hopper should last the life of the furnace lining. Modern furnaces, making up to 1,000,000 tons and over one one lining, may be in blast for six to eight years, so that a large amount of material has to go through the large bell and hopper, and this should be taken into account. It should not be necessary to do a major top repair, such as replacing a large bell and hopper, at any time except the relining period.

I have mentioned towards the end of my paper that a future development in furnace practice might be high-top-pressure operation. We have heard something about this from America, and further trials are being run there at the moment.

I think that, unfortunately, we get more top-line figures from America than the whole story; nevertheless it would seem that this may be something for the future. Some far-sighted person might design a furnace now for possible high-top-pressure operation in the future, because, after all, it is easier, and should not cost very much, to design the furnace when it is built new, whereas to patch-up or alter an existing furnace for high-top-pressure operation may not be an easy matter. It should always be possible to go back to ordinary blowing without much trouble or expense.

Blowing costs are amongst the highest costs on a furnace. To reduce blowing costs, we must think in terms of high-pressure steam. The gas turbine, however, might come into its own in this sphere and displace the boilers altogether; that is another development which should be kept in mind.

When laying-out any plant, provision must be made for future expansion, even though at the time you may think that the plant is as big as you will ever get it. One great difficulty which faces engineers who are trying to remodel and rebuild existing plant is that they are invariably tied up for room. Anyone who is thinking of new sites and new developments must keep in mind that in twenty of thirty years' time it may be vitally necessary in the national interests to expand the plant and make alterations.

Finally, one thing which must not be forgotten is the proper instrumentation of the blast-furnace plant. Adequate metering of electricity, gas, steam, and water must be considered in the initial stages in relation to the plant as a whole. It often happens that the provision of gas-flow measurement is considered as an afterthought or as an isolated application and not integrated. Then it is not always possible to find a sufficiently straight length of gas main to give accurate metering, and selection of the orifice position is difficult. Proper control of production and operating costs necessitates proper instrument layout and provision for their maintenance after the plant is running.

## DISCUSSION

Mr. **A. Bridge** (Appleby-Frodingham Steel Co.): After Major Brown's complimentary remarks about the Appleby-Frodingham South Plant I feel a little embarrassed in commenting on certain sections of his paper, but I should like to refer to the layout shown in Figs. 2, 3(*a*), and 4, and I will take them in that order.

In Fig. 2 it would appear that for the four-furnace plant shown, four cast-house cranes would be necessary whereas, with the re-siting of the stoves, the same four furnaces could be adequately served by two cast-houses cranes; for example, if the tap-holes faced each other, the cast-house cranes could be arranged to serve between pairs of furnaces.

In Fig. 3(*a*), I see a repetition of an all-too-common fault. Unfortunately it is not always apparent in the design stage of a new plant, but it presents itself very forcibly at the first reline. I refer to the built-in outrigger for bell handling. This should be designed to enable the bell and hopper to be lowered from the furnace top to the rail track in a vertical line, clear of all obstructions. Imagine what it means when a bell and hopper weighing 45–50 tons have to be pulled clear of the cast-house roof and canopy, to say nothing of weather hazards such as wind and fog. It is no easy task, and in addressing these remarks to the designers I plead with them to obviate such awkward arrangements in future designs.

A further comment I have to make on this bell-handling gear is that some form of lifting beam should be provided with which to lift the bell-trolley crane down, because to leave the trolley up there for a furnace campaign is to ask for trouble. If the trolley is wanted, it is wanted in a hurry, and should therefore be workable when required. On our South Plant, when we were planning the relining of a furnace, we found when we went to the top that the bell trolley was in an abominable mess, and we had to get it down by blocks and tackle (a very awkward job), and completely strip it. It took us about ten days to put it in working order, but we are wise now, and when we have finished the reline of a furnace we bring this gear down to the floor, clean it, and keep it ready for future use. To re-erect it on the top of the furnace takes only about 3 hr., as we have now put in lifting beams to facilitate this work.

As regards Fig. 4, I do not like to see the cast-house floor carved up like a Christmas turkey, and I know that blast-furnace managers will agree with me. Too much is made about the handling of large quantities of slag, but perhaps to us at Appleby-Frodingham it is second nature, because, for a make of say 500 tons of iron, we have to handle about 650 tons of slag. We have the slag ladles on one side of the furnace, and the hot metal ladles on the other side of the furnace, and we find no difficulty with this arrangement. I cannot, therefore, see the necessity for all the railway tracks in Fig. 4, with docks all ready to get filled up with iron and slag any time there is a mess at the tap-hole.

Fig. 10 shows pneumatic bell-hoists. I am on dangerous ground here, but I should like the author to say what advantage there is in the pneumatic bell-hoist as compared with the simple and efficient electric bell-hoist. The very look

of this photograph scares me, with all the mechanical gear, compared with the simple electric bell-hoist. There may be some advantages, but if anyone has tried it out I would like to know the advantages and the disadvantages.

The question of valves for the dirty-gas main is one which does not get very much attention. We at Appleby-Frodingham feel very strongly that the isolating valve in the dirty-gas main from a furnace should be of the goggle type, thermo-goggle or toggle-operated. The goggle valve is the only safe way to isolate the gas main from the furnace. Water seals are not reliable, as a slip at another furnace might blow the seal when men are in the main; more thought should be given on new plants to this type of valve, because with the ordinary type of sluice valve, as most engineers know, you are never sure whether it is completely shut or not, and, unless there is the provision for a spectacle plate in the main, perfect isolation is not assured. With the goggle type of valve, however, this hazard does not arise.

With regard to the auxiliaries (*a*) to (*g*) mentioned in Major Brown's paper—the electric lift to the top of the furnace, automatic stockline recording, and so on—we agree with the author that these are not refinements but are essentials for a modern furnace, and I am glad to see that somebody is bold enough to put that statement in print.

Now a word or two about slag ladles. Both Major Brown and Mr. Scott-Maxwell advocate the adoption of the large steam- or compressed-air-tipped slag ladle. Why? We at Appleby-Frodingham have been using, when available—and I say "when available" deliberately—12 of these steam-tipped ladles of 330-cu. ft. capacity for over seven years, and we have not as yet found their virtues: we know their vices and list them in the following order:

(1) Poor availability (often out for maintenance).

(2) Excessive maintenance (treble the cost of the orthodox type).

(3) Take two to three times as long to tip as the ordinary type.

(4) Not adaptable for bank-work extension because the bogie carriage extends so that the ladle cannot reach as near to the end of the bank as one would like.

(5) Difficult to re-rail after derailment.

(6) Vulnerable to spillage at the cast-house, and, knowing that the blast-furnace man's mentality is to make as much mess as possible, it can be imagined what it is like when the gear and wheels get full of slag; the mechanically operated ladle is therefore very difficult to keep clean and in working order.

Another point with regard to these steam-tipped slag ladles is one of those things which should not happen, but it does happen; no matter how good the blast-furnace operation, you cannot at times avoid getting iron into slag ladles. When this happens it is very difficult to tip these ladles, and the bigger the capacity the harder it is, whereas with a ladle which is rope-tipped by a locomotive, you can "yank it about" and so have a chance of getting the ladle empty, and that is a point which is worthy of consideration.

Finally, these ladles are very high in initial cost. I do not know the present-day cost of a 330-cu. ft. unit, but I should say that it is in the region of £4,500—probably more. For that figure you could get three ladles of ordinary type with an aggregate of twice the carrying capacity, and as far as we at Appleby-Frodingham are concerned, the blast-furnace superintendent, the traffic manager, and myself all prefer the rope-tipped ladle, and when we three agree there must be "summat in it" because we seldom do agree!

Mr. Scott-Maxwell states that screening should be the last operation previous to the ores being put into the furnace bunkers. We fully agree, but according to his Fig. 1 the wagons are tipped, and, after the primary and secondary crushing, can be passed to the stockyard if necessary and later reloaded *ex* stockyard. What happens then? The stone reloaded from the stockyard has already been crushed. I realize that Fig. 1 is diagrammatic, but I should like a little clarification. Does it mean that when you have reloaded into the railway wagons you have to bring these wagons back on the tippler, tip them, and put the contents through the primary and secondary crushers a second time?

Regarding the remarks in Mr. Scott-Maxwell's paper about furnace bells and hoppers, I think that we would all agree that a furnace bell and hopper should last a furnace campaign, and in my 35 years' experience I have never known one that has not done so, except through accidental damage or when, owing to circumstances, we had to put a "second-hand" set back in the furnace, knowing that we might have to change it later. I do not know whether others have had the experience of having to make a change in the middle of a campaign with a new bell, but it has not been my experience, even with large furnaces.

I am very keen on this Engineers Group, and very pleased that it has been formed. We engineers are now able to get together, state our problems frankly, and argue them out, and I sincerely hope that the formation of the Group will be a success.

Major **W. R. Brown**: Mr. Bridge referred to the layout shown in Fig. 2 of my paper. I can

assure him that it was not a haphazard decision to arrange the furnaces as shown. The merits were carefully analysed. There are not four cranes used; the two centre furnaces have a common cast-house crane. With the arrangement he suggests there would certainly be two cranes instead of three, but, on the other hand there would be three stove chimneys instead of two, there would be three passenger lifts instead of two, there would be a longer average distance for the blast to travel, and there would be less ventilation in the cast houses, a matter of importance in a warm climate. The extra crane is a useful piece of equipment, whereas there would be nothing to be gained from the extra chimney, passenger lift, etc. Hence I still remain convinced that the arrangement as shown is preferable.

An outrigger to give a clear run down to the rail track is well known to be desirable, but if certain other features have to be retained it is something which is well-nigh unobtainable, unless it has a terrific overhang. The situation is not quite so bad as might be thought from Fig. 3 (*a*), because the canopy over the ladles does not extend to the point where loads are lowered. We do not regard the task of guiding the descending load as one which presents much difficulty.

To have a lifting-gear beam that serves to lift the trolley from the outrigger runway is quite a reasonable addition to make when people as enlightened as Mr. Bridge are concerned, but unfortunately the plant designer has to show some discretion in the extent to which elaborations are taken. These matters should conform to the ideas of the maintenance engineers who will be responsible for the upkeep of the plant.

Mr. Bridge then asked what are the advantages of the pneumatic bell-hoist. The following are the chief claims :

(*a*) Lower initial cost and the occupation of less floor space.

(*b*) Independent sources of motive power (cold-blast system and compressed-air system).

(*c*) Adjustable speed of bell operation.

(*d*) Bells can neither be violently opened nor slammed shut.

(*e*) If an explosion occurs between the bells, the large bell can open and return without slamming.

(*f*) If both sources of air pressure fail, the bells automatically return to the closed position.

(*g*) Low maintenance and operating costs.

Let us see what is the consensus of opinion in the United States. Since 1939 some seven or eight electric hoists have been installed there, compared with 39 air-operated hoists. Today there are six furnaces under consideration or in course of construction in the U.S.A., and in each case the pneumatic bell-hoist is specified. There we have a display of opinion that is overwhelming, and this in a country where a great deal more experience has been amassed that on this side of the Atlantic.

I am not, I hope, to be accused of partisanship because the air-operated hoist happens to be a speciality of the people with whom we are associated in America. I deplore the segregation of designs into schools, and I would gladly see the best designs freely used and freely acknowledged in the plants to be built in this country. A careful reader of my paper will discern tributes to several designers.

I agree with Mr. Bridge's commendation of goggle valves for the isolation of gas mains. For the last eighteen years I have never willingly put in anything else.

It is most illuminating to hear what Mr. Bridge has to say about slag ladles. From the popularity of these ladles elsewhere, there must be some marked divergence of opinion. It is especially surprising to hear one who is a strong proponent of modern equipment so strenuously advocating equipment which has changed little in fifty years. I can at least reassure him that the cost of these ladles has not yet reached the figure he mentions. Anyhow, I confess to feeling a little discouraged !

Mr. Bridge mentioned, in connection with Mr. Scott-Maxwell's paper, that he invariably found that his bells and hoppers lasted a campaign. I should like to ask what is the average length of the campaign to which he refers. It is obvious that we shall need some very robust equipment if the original bell and hopper is to last a campaign equal to the latest American record of 3,750,000 tons of iron. Perhaps Mr. Bridge will tell us the average life of a furnace where the bell and hopper lasts for the full campaign.

I should like to thank Mr. Bridge for his contribution, because it is very valuable to hear opinions expressed on each side. I certainly think that every point that he raised merited discussion.

Mr. **I. S. Scott-Maxwell** : With regard to pneumatic bell-hoists, I have used electric bell-hoists for many years and found that they gave no trouble, but on a recent furnace we ordered a pneumatic bell-hoist. I do not think that there is anything to be frightened of in the mechanics of it ; it is quite simple engineering. We changed over, not from any dissatisfaction with the electric bell-hoist, but because we felt that the pneumatic bell-hoist gave better control of the bell operation, to the extent that it was possible to vary more easily the speed of opening and the speed of bell travel. That has some effect on the distribution in the top of the furnace, depending on what kind of ores you are using. Whether any great benefit will be obtained in practice or not I do not know,

but we felt that there was an added advantage there which was worth going for.

In Fig. 1 of my paper, which I admit is a little sketchy, the ore is shown coming in wagons through two sets of crushers, but it is not intended that having stocked it it should come out of stock into wagons again, but that it should come out of stock into the flow of material. How that is to be done I do not know at the moment, because it has never been thought out as far as that. I have shown there something called a mixing plant. There is no such thing in existence at the moment, but the idea would be to stock the crushed ore and then to bring it from the stock-yard into the flow of materials again and mix it in the proper proportions, after which you would screen it into the graded sizes and charge it to the furnace. The "mixing plant" really takes the place of the "bedding plant" used with home ores. It is much simpler, however. The effect would then be that you have high-line bunkers filled with a mixture of different ores but all of the same size-grading.

Mr. **A. Bridge**: There are one or two points which I should like to make clear to Major Brown. We are not asking that all lifting gear should have other lifting gear to move it ; it is just a question of special provision around the furnace. These large modern furnaces are economic units, and, therefore, when relining a furnace it is very necessary that it should be out of commission for the minimum of time ; it is for that reason that we ask for these additional facilities. The pulling-out of the bell to clear the cast-house roof (and in our case the canopy as well) is a very difficult job ; there is no question about that. Some people say that we should take a piece of the cast-house roof out, but that is not ideal : we want to be able to get the bell out, down to the floor, and away as quickly as possible, so as to get on with the relining work. The last furnace we relined was one of our big furnaces and we did the complete job, from blowing-out to blowing-in, in 43½ days, so you will understand the necessity for these lifting facilities.

With regard to the pneumatic bell-hoist, I am not one of those who assume that everything that is done in America is always the best. American practice and British practice differ considerably, and we must therefore weigh and decide carefully on any American equipment to ascertain its suitability for our practice.

Major Brown referred to the life of furnace bells. Our large furnaces at Appleby-Frodingham, on a make of about 500 tons a day (which is equivalent to an American make of 1,000 tons a day), produce in the region of 1,000,000 tons of iron in a campaign of about seven years. Although when the bells came out they were worn, they were not beyond further use. I still think, therefore, that we could probably go two campaigns with the same bell, but we shall have to find that out in practice.

Mr. **W. Banks** (Cargo Fleet Iron Co., Ltd.) : As an operator, I am interested not merely in the handling of large quantities of materials going into the furnace, but in handling the stuff coming out ; there is therefore one point which I want to raise regarding Fig. 4 of Major Brown's paper. I support Mr. Bridge when he says that the slag ladles could be put on one side of the furnace, even though it means two slag notches on one side of the furnace. On the diagram we have two slag notches and the tap-hole within a radius of 90°. I think that that could be widened. There is a big danger in handling large quantities of slag and iron with three outlets within a radius of 90°, and I think that it would be safer to have the slag notches further round to the back of the furnace. Looking at it from the slagger's point of view, to have these very long slag roads is not a good thing at all, and may hinder the furnace rather than help it. Personally, I would much sooner see a long iron road and a short slag road, rather than the other way round. Normally it is much harder to get slag away from the furnace than to get iron away. I do not like the idea of the iron road cutting across the centre of the cast house. Having worked at the South Works for a short time, I can truthfully say that they can certainly handle large quantities of slag and metal very easily with their set-up.

Coming to the question of furnace design, I have always been amazed that we never cut down the number of columns to, say, five or six. I cannot see—I am not an engineer—why the number of columns should be dependent upon the number of tuyeres. I think that we should have some design where we could have a standard number of columns, say five or six, whether the furnace had ten or twenty tuyeres. When you consider the space that is taken up round the mantle by the columns, and that we have plate coolers right up at the top of the bosh, it will be realized that sometimes it is very hard to maintain pipework and to examine plate coolers because of this. I have seen many instances where plate coolers could not be drawn on account of the columns ; in the event of the plate coolers developing a leak, the only thing to do was to take the water off and try to fill up the cooler with some refractory material. If we could have the mantle much wider and the columns further away from the furnace we should have greater accessibility, and it would certainly enable such a job as changing coolers, tuyeres, and so on to be done much more quickly.

With regard to gas valves in the dirty main,

there is no doubt that the thermal goggle valve is the one to use, and I think that all plants should have it installed. When a furnace is shut down and the men working inside the bell and hopper are working with the bell out, as we had to do recently, it is very worrying to the furnace manager when he knows that he has a faulty gas valve. The old practice of having a butterfly valve in the dirty-gas main should be wiped out entirely.

On the question of the electric bell-hoist *versus* the pneumatic bell-hoist, I think that Mr. Scott-Maxwell is right when he says that with the pneumatic hoist you have greater control over the speed of the bell, and there is no doubt that this does influence the formation of the stockline. With regard to charging, however, it seems to me that with the advent of expensive ore preparation, crushing, and grading, we shall probably have some other method of depositing materials in the furnace. I think that I am right in saying that the McKee top was designed in the first place to do away with segregation. If we are charging material in layers all of the same size, it seems to me that the problem of segregation is disappearing, and we may find that when we get on to all-graded material we shall come up against different problems as far as stockline formation is concerned.

On this question of steam-tipped slag ladles, there is no doubt that with the old rope- and chain-tipping ladles we could get a good throw and could skull the ladles better, but from the point of view of handling large quantities of slag I think that the steam-tipped ladle is the best. I was very pleased to hear Mr. Bridge say that it was impossible at times to prevent iron going into the slag ladles. He is the first engineer that I have ever heard say that! As far as furnace operators liking messes is concerned, there is one here who does not. After all, it generally means being out of bed all night.

Major **W. R. Brown** : I am grateful to Mr. Banks for his comments on the layout shown in Fig. 4. I might let him into one secret ; a plant designer likes to see a job which looks well and of which he can be proud. A slag notch towards the rear of the furnace interferes with the cast-house floor ; and we like a nice, uninterrupted floor. That is probably an aim which we should make secondary to the features of which Mr. Banks speaks. There seems to be a very strong liking in this country for two slag notches, but many furnaces, both here and abroad, work extremely well with only one, and this certainly permits a much clearer cast house round the rest of the tuyeres.

The comments from those who have worked in Lincolnshire with regard to the feasibility of handling their large quantity of slag are most useful to those concerned in the design of plants. It is most helpful to know that they have an arrangement which meets all requirements.

On the question of the number of columns, I agree with Mr. Banks. Columns are an evil ; I would hardly say a necessary evil, because I have an idea that some day we may build furnaces without columns. I have found no one yet who will take the responsibility of trying this innovation. My contention is that when the blast-furnace had a hearth of about 8 ft. and a bosh of about 28 ft., columns were essential to support a structure shaped like a peg-top. Now, with bosh angles of well over 80° I am far from satisfied that it is an insurmountable difficulty for a furnace to be designed without any columns whatever. I do not know whether those who have been in Germany found any furnaces so built, but I did see a publication where, for their wartime emergency plants, a standardized blast-furnace without columns was advocated. If not in my own active lifetime, then certainly within the lifetime of some of you, I feel sure that furnaces will be built without columns.

Where cooling plates become difficult to manipulate—and there is difficulty with some—we take the precaution of using what is known as a duplex plate, in which there is a separate inner and outer compartment. If the outer shell of the plate is burnt, the water can continue to circulate in the inner part only, so providing a double life in the one plate. If the plate is burned a second time we arrive at the position to which Mr. Banks referred, where we have to take the water off and try to plug the cooler, presumably with clay.

I should like to thank Mr. Banks for his kind commendation of goggle valves. He referred also to butterfly valves in dirty-gas mains. These, I agree, were abominations.

On self-tipping ladles there has now been a divergence of opinion, two for and one against. By no means all of us have had experience of them, but it would be most helpful to the people who have spent a good deal of time and trouble on this subject if we could have further expressions of opinion.

Mr. **T. Carruthers** (Workington Iron and Steel Co.) : I regret I cannot quite agree with Mr. Scott-Maxwell's recommendation that the charging gear of blast-furnaces should be designed to cope with the charging of scrap, unless the size and weight of the scrap is kept under rigid control. If the scrap is small and light there is, of course, no difficulty, and the ordinary gear will accept it, but it appears nearly an engineering impossibility to design the gear so that it will permit the haphazard use of scrap ; also I contend, with all due respect, that the blast furnace is intended for smelting, and that the correct thing to do with scrap is to use it in the steelworks' melting

furnaces. I am fully aware that blast-furnace-production figures can be made to appear, to the uninitiated, remarkable by the unlimited use of scrap, but it is my opinion that such practice is to be deplored.

I have noticed on drawings of German blast-furnace lines that in some cases they appear to use what looks like a fixed distributor, and that they use on quite large furnaces a comparatively small bell, the materials falling from this on to a large-diameter cone fixed in the throat ; they thus get all the benefits of a large bell without the high cost of a large bell and the difficulty of its manipulating gear. If any of the members present have any knowledge of this device, I would much appreciate their remarks. I am particularly interested, as I consider that the cost and hazard of the super-large bell and its operating gear limits the design of blast-furnaces. I have not used a 15-ft. dia. bell as is in use on some of the furnaces at Appleby-Frodingham, but I have been very impressed by the improvement in the operation of one of the Workington furnaces where, on relining, we fitted a 14-ft. dia. bell instead of the 11 ft. 6 in. dia. previously used. The use of a small bell with a large-diameter hearth, of course, gives a fast batter to the inwall, to which some operators give great importance, but I notice that the Germans, when they use this device of a large-diameter fixed-cone distributor, allow the inwall batter nearly to disappear, apparently without ill effect on operation. To obtain correct distribution, the bell itself must be in perfect balance. This should be achieved by " machining-off " redundant metal, as I have found that added balance-weights, when used to correct errors in balance, always work loose sooner or later. I have used air cylinders for bell operation of mechanically charged furnaces, but I have also used steam cylinders, hydraulic cylinders, and electric winches for the same purpose, and I am perfectly satisfied with, and prefer, the last-named.

With regard to rope stretch, which was a chronic trouble during the War, when one had to " make do " with any quality of rope available, I suggest that it could perhaps be dealt with, with the minimum of interruption to production, by making the position of the head pulleys adjustable, or by providing some other such adjustment ; on the other hand, the provision of more suitable ropes may render this complication unnecessary.

I have experienced exactly the same trouble with bell-changing gear that Mr. Bridges referred to, and I fully agree with him that the best thing to do to make certain that it will function properly when next required is to lower it down to the ground and keep it there when not in use.

I am a strong advocate of the use of the so-called thermostatic goggle valve for isolating the furnace from the gas mains. They are completely reliable and have many advantages over other devices for this purpose.

The very considerable outlay involved in the provision of steam-tipping slag ladles is justified when manufacturing hematite, but the problem may be different when dealing with the huge slag volumes produced when using home ores for basic iron. A good class of man is required for their maintenance, and if properly used they are quite safe.

I fully agree with Mr. Scott-Maxwell's opinion that plants running on imported ores should be required to use a maximum of three classes of ore only. That is a state of affairs we all want, but, of course, they must be the correct ores. I trust there is someone here from the Ore Board, and that they have made a note of this.

The recommendation that ores should not be screened until they are lifted from stock may be an ideal, but it is very difficult to carry out. The equipment manufacturers will be inclined to endorse it, as to carry it out properly much more plant is necessary.

With regard to cooling plates and columns, I consider it is a crime to install a plate in such a position that it is impossible to withdraw it when desired. Major Brown has rightly said that a plate of the duplex-flow type can be used in such a position, but I have often found that when a plate fails a replacement plate will fail shortly, and sometimes a third fails. This, I suppose, is due to some peculiarity or fault in the distribution of materials or, more likely, of the blast. When a plate is required behind a column, instead of using an ordinary plate that cannot be changed I find it is completely satisfactory to employ a pair of so called " skew " plates. These are special plates, half the usual width, one being inserted " on the skew " from each side of the column. This idea may slightly elaborate the water-pipe system, but it is certainly most effective, and such plates can be withdrawn in the ordinary way when desired.

Major **W. R. Brown** : With regard to the complications found on the charging-control panel in Fig. 9, it is perhaps a great deal more formidable in appearance that it is in actual fact. We hope that for 365 days in the year the operator will use only the switch numbered 28 in the diagram. Most of the other switches are for use on the rare occasions when certain operations have to be controlled by hand while adjustments are going on. If you would prefer them to be hidden elsewhere in a secret cabinet it could be so arranged ! Our aim has been to reduce the operation to its most simple form, though we seem to have succeeded in making it appear most formidable to some.

Means for taking-up rope stretch have been mentioned twice in the discussion. That is something which is exercising our minds to the very utmost. We have investigated countless different devices and ideas, including adjustable sheaves, in trying to find a quick and easy method of shortening ropes, but we have, so far, failed to find satisfaction. We have made some partial improvements, but the ideal solution still eludes us.

Mr. Carruthers' comments on slag ladles have somewhat revived my spirits. It seems hardly credible that hundreds of these can be in service in some ten different countries and yet, as an earlier speaker stated, be inferior to the old-type equipment.

Mr. **I. S. Scott-Maxwell** : Mr. Carruthers seemed to indicate that my two points about the handling of scrap and screening after stocking were too difficult to achieve and perhaps not altogether necessary. They are, I know, extremely difficult to achieve, but that is no reason why we should not attempt to solve these problems. The fact of the matter is that, as we all know, fuel economy is of paramount importance. We have to get the lowest possible consumptions, much lower than we are getting at the moment, and these are two ways of doing it. To that end much thought, design, and development are necessary and justified. I cannot say at the moment how it is to be done, because I have not given it sufficient thought, but it seems to me to be quite possible and not beyond our capacity.

Perhaps I ought to say a word about columns. Some mention has been made of German furnaces. The design of German furnaces has developed in a different way from that of the British or American design, inasmuch as the top structure is carried on a steel framework which is built up from the ground level separate from the shell casing. The German furnaces therefore have columns, but they are not quite the same thing as in Great Britain. There is one furnace in Germany which has no columns in our sense of the word, namely, No. 5 furnace at Bochum. This is built with a steel-plated shell from the hearth right to the top platform, and it sits on its own base ; but the head gear and the charging mechanism are carried on a separate steel framework, built up in a square outside the furnace shell, so that the weight of the top gear is not carried by the furnace shell itself. Furthermore, provision for taking the weight of the shell on this framework has been provided, but so far as I know not used. It should also be remembered that provision for expansion must be made at the furnace top. This might complicate matters if a shell were designed with no columns, in fact it would probably mean that the skip bridge would require to be supported entirely independently of the furnace stack.

Mr. **T. Powell** (Messrs. Dorman, Long & Co. Ltd.) : I think it is agreed that the McKee top is the best form of distributor that has been installed on the furnace top and that some credit should be given to operators for the very good use they have made of it.

Research has brought forth another distributor with more flexibility than the McKee top, but the great difficulty is the engineering problem of getting it installed. I refer to the Saunders top.

The very desirable layer charging by sizes, mentioned by Mr. Scott-Maxwell, would be much simplified if we could be sure of a burden made up of, say, only three different kinds of ores. With increased kinds of ores the required bunkers at the furnaces become a proposition which is not very practical.

I question the statement made by Major Brown that zoned checkerwork is being ousted by fillings of uniform cross-section.

From information that I have, there have been 134 stoves filled with zoned checkerwork during the past 12 years in this country, and there are eight at present under construction. During the experience I have had with zoned checker fillings, nothing has occurred to warrant a change.

Major **W. R. Brown** : I am glad that Mr. Powell raised the question of the revolutionary distribution ideas of Dr. Saunders. I do not feel in the least competent to say whether or not the improvements which Dr. Saunders' manifold experiments foretoken would be achieved in actual practice, but I am very strongly of opinion that the industry should find means of testing his theories. I think it is quite possible that if his and our hopes are fulfilled we may find that many problems connected with the preparation of ore would solve themselves. It is perhaps trespassing upon this afternoon to refer to ore preparation, but there must surely be a limit to the amount of preparation that we can afford to do, particularly upon low-grade material. It would be a happy solution if we were to discover that the Saunders charging apparatus could digest a less well-prepared diet, and so save much of the money and effort spent on the preparation of raw materials.

I have had a look at Dr. Saunders' ideas in diagrammatic form, and they do present fairly profound engineering problems. I do not think that those problems are insuperable, but the project will take time and money to develop ; firstly to produce on paper what seems to be a practical method of attainment and secondly to try it out on a furnace, moreover on a furnace which in all other respects complies with today's ideas of what a furnace should be. The test must be such that we can definitely relate the results

to the particular piece of apparatus with which we are experimenting.

I trust that I may be excused from entering into a full argument on zoned checkers. Certainly there have been many zoned-checker systems installed in this country, and I believe that they are nearly all giving satisfaction. The only question which arises is whether in any new installations we are actually benefiting from some of that zoning. A diagram showing the temperature at various levels in the checkerwork makes it apparent that the heat interchange in the bottom section is relatively small, hence a system which uses the greatest brick mass where the heat storage is least must be wasteful of material, even though the results are not inefficient. I merely reiterate that some of the early exponents of the zoned system have now abandoned their previous theories and advocate chequers with uniform passageways.

*Written Contributions*

Mr. **D. C. Hendry** (Messrs. Stewarts and Lloyds Limited) : Major Brown's paper on the blast-furnace of today has very many points of interest, not the least of which are the diagrams in Fig. 1, which show the composite lines of various furnaces built during the decades 1920–30, 1930–40, and projected from 1946 to the present time. No doubt the furnace lines in the different groups of sizes cover furnaces intended to operate with foreign ores and with home ores, or with mixtures of the two. The point which strikes one is that to all intents and purposes the furnace lines for use with the different kinds of ore are more or less identical, the main differences being those arising from the difference in hearth diameters used. It is noticeable too that the lines of the furnaces projected for the post-1946 era indicate that a considerable increase in heights is being associated with expanding diameters. No doubt the larger furnaces will give greatly increased outputs, and it is necessary to ensure that the stock is properly prepared before reaching the hearth, thus rendering an increase in height essential. It would add to the interest and usefulness of the diagram if, for the three series of composite lines, a table were prepared giving the type of work each furnace depicted is doing or is expected to perform, together with the number of tuyeres, rate of stock descent, coke consumption, etc., and I hope Major Brown will be able to furnish this information.

As regards Fig. 2, which shows the arrangement of a four-furnace plant for installation abroad, there are many points on it which call for comment. No doubt, however, the layout has been very largely dictated by the clients' wishes. One point which calls for some comment is that the sinter plants, located at the end of the ore yard, apparently discharge sinter into it, and this sinter appears to be handled entirely by the ore bridge. I do not think that this is a good arrangement and, while no doubt the point has been considered, it appears to me that it would be wise to employ some additional means of loading the sinter from the stockyard into the transfer cars serving the furnaces. The ore bridge is not a highly mobile piece of equipment, and it usually has many other duties associated with feeding the furnaces which would compel it to be away from sinter loading for considerable periods of time. It can be visualized, therefore, that there may be interruptions to the flow of sinter to the furnaces, with some upset to the regularity of charging. This may or may not be of importance to the plant projected, but it certainly would be in certain types of practice in use today. Perhaps Major Brown would like to comment on this point also.

Finally, I should like to show four examples which illustrate the difference between the older type of blast-furnace top and the more modern McKee type. Fig. A shows the old type of revolving top. Owing to the increase in gas pressure which has occurred as the years have gone by, we get the deposition of tremendous quantities of dust. The foggy appearance of Fig. B is due to the tremendous amount of escaping gas. We have to stop down these furnaces for two or three hours at week-ends to clear the accumulation of dust away. Fig. C. shows the difference with the McKee type of top which we have on two of our furnaces. There is hardly any dust to clear away at all. Fig. D. is a close-up view of the method of supporting the revolving top. There is a ring, slightly conical, supported by six rollers of the type shown, and the top cannot move up or down. This top has served for a period of years

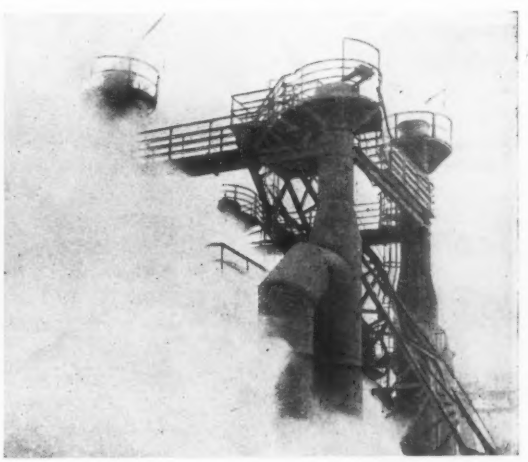


FIG. A—Gas leakage with old type of revolving distributor

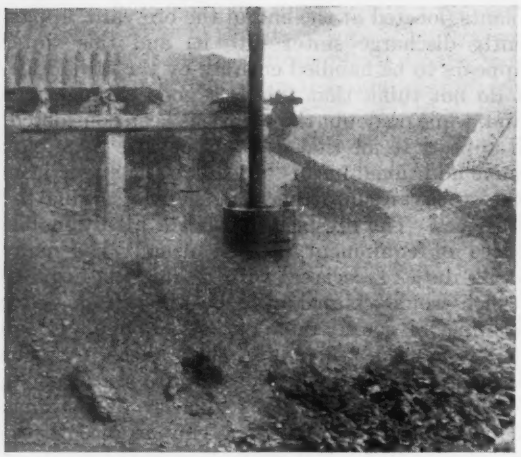


FIG. B—Deposition of dust on furnace top with old type of revolving distributor

and only minor adjustments have been necessary.

Major **Brown** : Some mention of furnace lines was thought to be relevant to a review on furnace engineering, but restraint was exercised to avoid following this trail into the territory of metallurgy. The author hoped to evade any digression by disguising individual lines in composite drawings and presenting them merely to show how far any change affected engineering. The points upon which Mr. Hendry seeks information would make suitable material for a paper by an operator. In the present instance, the author has no first-hand knowledge of some of the furnaces illustrated in the drawings ; they were assembled solely to typify the furnaces that were being built during periods which are more or less distinctive.

For the purpose of the present paper it was hoped to show how furnace lines were becoming stereotyped, irrespective of the particular materials

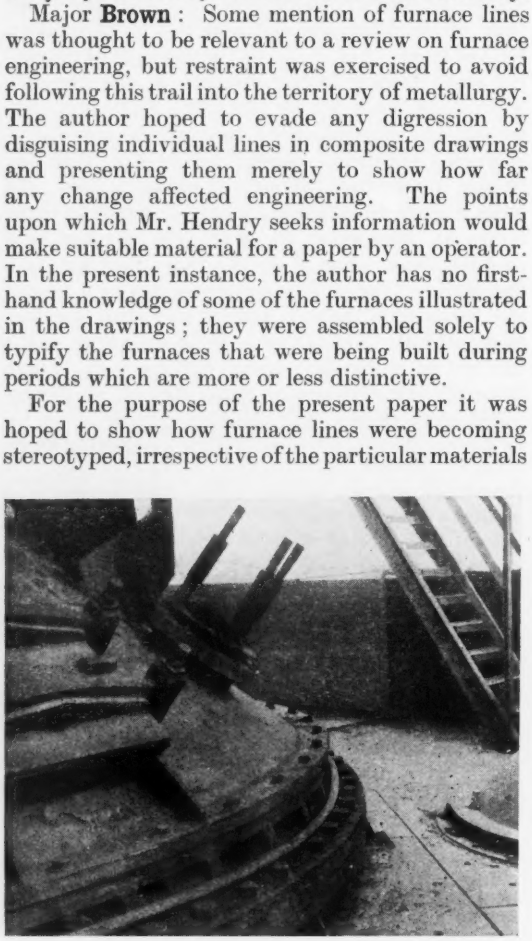


FIG. C—Furnace top with McKee type distributor

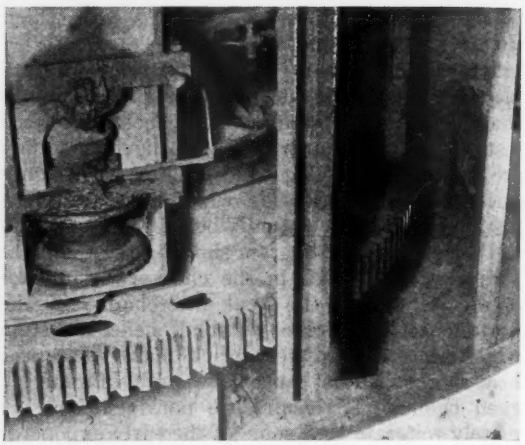


FIG. D—Method of supporting revolving distributor

to be smelted. Within certain limits, the inference may be drawn that furnaces today do not vary much except in accordance with the required output, and the height, being the chief variable for this can be governed by the quality of the coke.

Many facts have been taken into account in proposing that a sinter plant should discharge into the stockyard. There is much to be gained by keeping the production of the sinter plant and the rate of consumption of sinter in the furnaces independent of each other. In the arrangement shown in Fig. 2, when once a stock of raw fines and a stock of the sinter has been established, the furnaces and the sinter plant can pursue their independent courses. It is also alleged that the mechanical qualities of the sinter will be improved by avoiding the shock quenching which is always necessary when the material, as produced, must pass immediately to skips, bins, transfer cars, etc. The load on the ore bridge has to be considered, but the bridge in question has otherwise only to stock and reclaim the small variations which arise from inability exactly to balance deliveries of ore with consumption. It is not expected that the bridge will be occupied in handling sinter for more than 2 or 3 hr. per day.

The idea of locating a sinter plant as shown in Fig. 2 occurred to us as a novel and logical idea based on a wide—though not an intimate—knowledge of many installations. We must relinquish any claim to novelty, for we now know of more than one similar arrangement in America, notably that at Republic Steel, Warren, as described by C. J. Duby.* The thought, for which we were ready to claim credit, may in fact by an innocent act of plagiarism. We had doubtless read Duby's description, though when we

* *Iron and Steel Engineer*, 1945, vol. 22, May, pp. 39–42.

planned Fig. 2 we were not conscious of inspiration from without. In any case, Mr. Hendry will probably agree that the arrangement of a sintering plant must be largely governed by conditions, and these can vary vastly. The plant in question exists, so far, only on paper, and much may change before it is an accomplished fact. One aim of this meeting was to ventilate current ideas, and some of the contributions to the discussion show the value that can be derived from the interchange of views.

Mr. **I. C. Malcolm** (Messrs. Pease and Partners, Ltd.) :

*Zoned Checkers*

Major Brown refers adversely to zoned checkerwork. It is our experience that zoned checkerwork has great advantages in that the rate of heat transmission to the brickwork is directly proportionate to the velocity of the gas. Therefore, as the temperature drops the velocity drops unless voidage is proportionately reduced ; this is the value of zones.

All the stoves shown have **D**-shaped combustion chambers. In our experience this is a weakness which leads to by-passing of gas and blast through the combustion chambers, and we have found round combustion chambers to be more satisfactory.

*Crude-Gas Mains*

Properly designed crude-gas mains with dust bogies on a gantry give no trouble, and there may be some benefit with a long gas main. This is in a case where it is not possible to get adequate dustcatchers and so avoid some carry-over on to the gas-washing plant.

*Pig-Casting Machines*

The runners on our pig-casting machine are still sand silled. Some improvement should be possible in this item ; we have tried carbon, but this seems to have a very limited life. Whilst the casting machine satisfactorily handles the iron produced, I am not yet satisfied in a number of important details, particularly drainage, when making high-silicon iron, unless very adequate arrangements are made for dealing with the substantial amount of graphite, which separates out and chokes the drains.

The design of links and bushes has been improved but can be improved still further, as at present constant and regular changes of links and bushes are essential in order to avoid a high loss of iron in the form of shot. Scantlings of steelwork structure supporting the machines should be greater to offset the abnormal amount of corrosion due to the large volume of steam, and it is suggested that some effective method of galvanizing or some other form of protection would be helpful in this respect.

Disposal of the pigs is another source of trouble. The best method would appear to be to eject them direct into strongly constructed steel bogies to be taken to a separate quenching tower of the coke-oven type, thus keeping the steam and graphite, etc., involved in the quenching procedure away from the plant.

Our cost of moulds is approximately 2*d*. per ton of iron cast, or 2 lb. of moulds per ton of pig iron.

*Riverside Stockyard*

Presumably material to be transported from the riverside stockyard (Fig. 2 of Mr. Scott-Maxwell's paper) to the crusher plant can be taken by belt, thus avoiding the use of wagons.

*Hot-Blast Valves*

We suggest the use of mobile cranes for the changing of hot-blast valves. There appears to be a future for the gas turbine as a prime mover for the driving of blowers and generators.

*Steam Generation*

A steam temperature of 1650° F. is very high and would be troublesome on valves and fittings. At the Croydon power station, even 900° F. was found very troublesome.

PROCEEDINGS OF THE AFTERNOON SESSION : 2.15 P.M. to 4.30 P.M. :

## Discussion on SOME NOTES ON RECENT AMERICAN BLAST-FURNACES*

*by T. H. Stayman*

Mr. **T. H. Stayman** (Messrs. Head, Wrightson & Co., Ltd.), introducing his paper, said : I have a few slides which I should like to show. Fig. E shows the receiving hopper which takes the ore direct from the skip and passes it through the small bell. The rollers are shown, and the enlarged manhole so that the small bell can be changed if necessary. Fig. F shows the superimposed electrostatic precipitators. The claim made for these is not that they are cheaper and not that they give a cleaner gas, but that they are useful for installing in existing plants where shortage of space makes it difficult to put the precipitators on the ground.

I was very surprised in America to find the number of stockhouse bins which were hand operated. I expected them to go in more for mechanically operated bins, but a large number of them are of the type shown in Fig. G.

Fig. H shows the top part of the furnace with the offtakes first connected in pairs, and then the pairs connected, and a single downcomer. Fig. I is a view from the other side, showing the trolley.

* *Journal of the Iron and Steel Institute*, 1947, vol. 155, Jan., pp. 136–140.

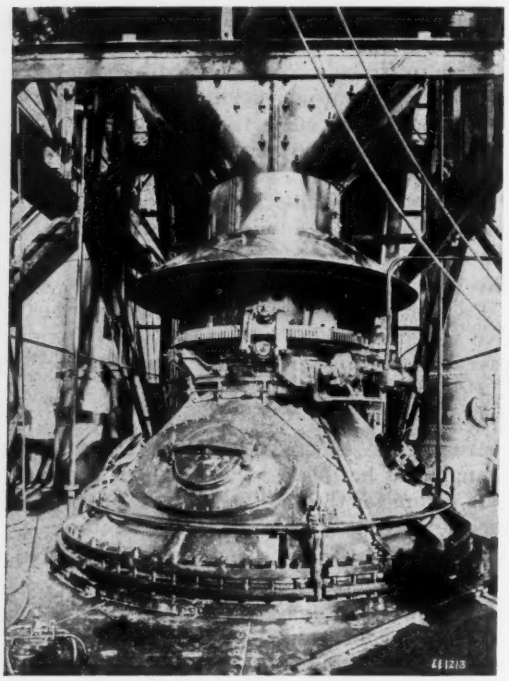


FIG. E—Furnace top, showing receiving hoppers

Some of the large American furnaces have a small lifting beam with a block for dealing with the trolley.

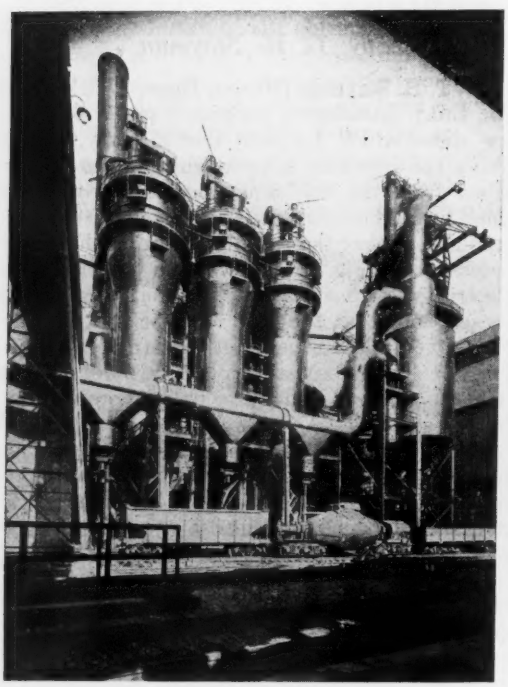


FIG. F—Electrostatic precipitators

*The speaker then drew attention to a number of misprints in his paper as published in the January* Journal, *and gave the following corrections* :

Page 136 : In the data for furnaces *A*, *B*, *C*, and *D*, the figures for bosh angle should read as follows :

| | *A* | *B* | *C* | *D* |
|---|---|---|---|---|
| Bosh angle | 81° 28′ 9″ | 81° 28′ 9″ | 81° 28′ 9″ | 81° 40′ 27″ |

Page 138 : In column 2, line 7, " 250–300 sq. ft." should read " 2500–3000 sq. ft."

Page 140 : Table I should read as follows :

| | Gas Volume 235,000 cu. ft./min. | | Gas Volume 210,000 cu. ft./min. | |
|---|---|---|---|---|
| | 3 Units | 2 Units | 3 Units | 2 Units |
| Inlet dust loading, grains/cu. ft | 0·25 | 0·25 | 0·15 | 0·15 |
| Efficiency, % | 95 | 85 | 96–97 | 87–90 |
| Outlet dust loading, grains/cu.ft. | 0·0125 | 0·0375 | 0·006–0·008 | 0·02–0·025 |

## DISCUSSION

Mr. **A. Bridge** : I am sorry to refer to the ubiquitous slag ladle again, but on page 138 of this paper, in the third paragraph of the first column, the author refers to five slag ladles of 200-cu. ft. capacity. This is a little puzzling, in view of the remarks previously made about slag ladles of 400-cu. ft. capacity. Can it be that our American friends are reverting to small ladles ?

FIG. G—Hand-operated stock-house bins

Can the author say whether the popular use of large ladles in America has something to do with electric traction as used over there, and therefore that facilities for tipping ladles by locomotive are not available as in this country ?

The author's slide showing a cat-head over the top of the bleeders, is, he apparently thinks, the answer to a maiden's prayer, but it has not entirely satisfied me. Bleeders on modern furnaces are very important items, gas is fuel, and leakage at the bleeders usually means trouble for the engineers, because the wastage must be stopped.

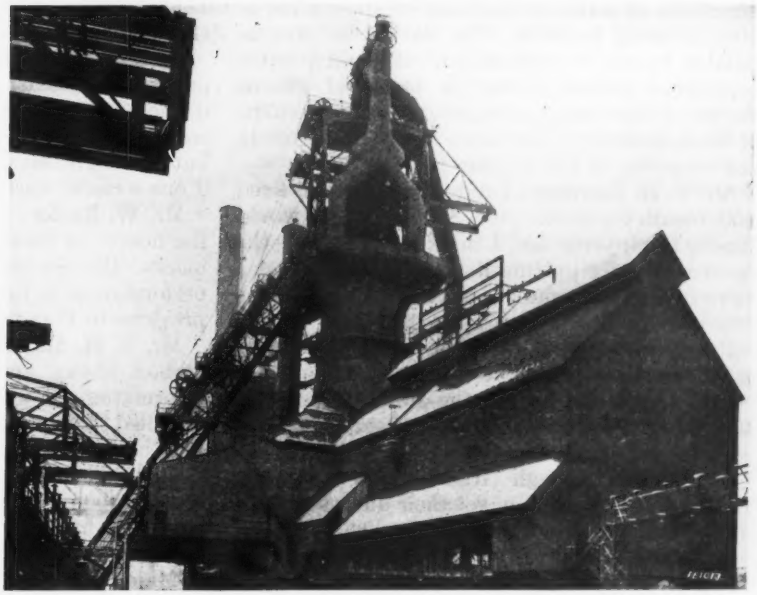


FIG. I—General view of furnace top

To change a bleeder —which on a modern furnace may weigh from 25 to 30 cwt. and be, say, 200 ft. above ground level—is not an easy job, but nevertheless, there is no necessity for the elaborate cat-head shown on the slide, and we have got over the difficulty by using a simple davit which can be erected *in situ* within an hour and dismantled again on completion of the bleeder repair ; the possibility of serious corrosion to lifting gear in such an exposed place is thus avoided. If we can help our American friends by sending them details of this simple device, we shall be pleased to do so.

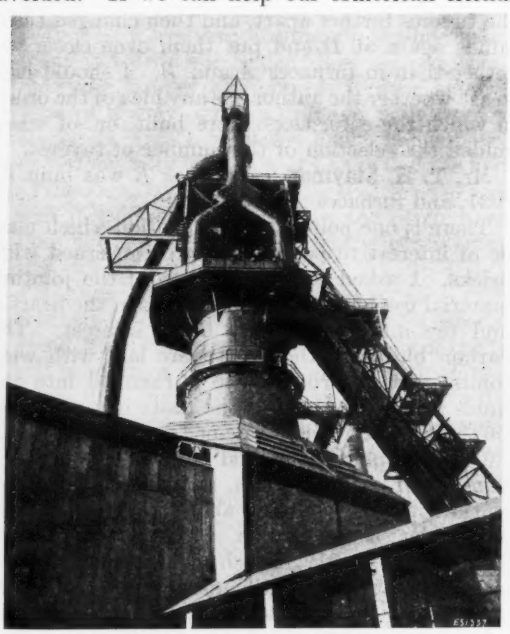


FIG. H—General view of furnace top

Mr. **T. H. Stayman**: Most of the ladles that I saw were the big steam- or air-worked ladles, but there are some plants where it is not convenient from the point of view of running clearances to put in the big ladles, and in the furnace in question the slag is normally run into a pit and granulated, and the smaller ladles are put in simply as a standby.

I do not remember seeing any chain-dumped ladles, and last year, when I had an American friend over here, we brought him to your plant and yours were the first chain-tipped ladles he had seen.

I am afraid that I may have misled Mr. Bridge about the cat-head. When I looked at the photograph I thought it showed the cat-head for dealing with the bell-handling trolley. I have a drawing of that cat-head which I will send to Mr. Bridge if he would care to have it.

Mr. **D. Kerry** (Messrs. Guest Keen Baldwins Iron and Steel Co., Ltd.): I wonder whether during his visit to the U.S.A. the author noticed the incorporation of a monorail either slung underneath the bustle pipe or in its vicinity ? Everybody appreciates that the approach of the cast-house crane to the furnace itself is naturally limited, and I feel that a monorail capable of accommodating a block for handling the tuyeres would be quite a useful addition to the plant.

Blast-furnace operators appear to make a habit of using every gallon of water available for the cooling of the furnace. This often makes for overcooling, as no appreciable rise in the temperature of the outgoing water takes place. Getting large

quantities of water to its point of application is often a costly business. Can the author give us reliable figures for the amount of cooling water considered necessary, say in terms of gallons per ton of coke burnt or in gallons per 1,000 cu. ft. of blast, or in any other known material figure in the operation of the furnace ?

Mr. **T. H. Stayman** : I did see a monorail fixed underneath the bustle pipe. I know that it would handle the tuyeres, and I think that that was the main reason for putting it in. The figure that I have in mind for water is that a furnace making 600 tons of iron a day used 3,000,000 gal. of water per 24 hr. on the bosh hearth, and they take 500,000 gal. out of that 3,000,000, which is re-pumped for cooling the stack. Those are the only figures that I have in mind, but I will write to you further on the subject.

Dr. **T. P. Colclough** (Iron and Steel Board) : In Table I, how do they get their dirty gas going in at 0·15 grains/cu. ft. ?

Mr. **T. H. Stayman** : Those are the figures going into the precipitator.

Dr. **T. P. Colclough** : What preliminary cleaning is done for that ?

Mr. **T. H. Stayman** : It goes through a washing tower.

Dr. **T. P. Colclough** : It must be a very good washing tower. Is the statement on page 139 correct, namely, that the pressure drop through the cleaner is 22–30 in. ?

Mr. **T. H. Stayman** : On that particular cleaner, yes. When I was told about it I was rather surprised, and I asked them to verify it, and that was verified as being the pressure drop.

Mr. **T. Carruthers** : Can the author please supply any statistics showing the use of disintegrators and the use of precipitators in recent blast-furnace-gas cleaning installations made in America ? This information would be most useful, as we are considering extensions to the gas-cleaning plant at Workington.

Mr. **T. H. Stayman** : I will endeavour to obtain that information.

The **Chairman** : In the superimposed type of electrostatic precipitator, owing to the fact that the wires must hang vertically and the gas goes down in parallel—unlike the horizontal ones, where it goes through in series—if there is a trip-out the precipitator is not going to work at all. With the ordinary type of precipitator, where the wires are vertical and the gas is travelling horizontally, even if one bank trips out the others will go on cleaning. Some figures are given on page 140, but presumably they are with all the banks switched in. If you get a trip, it seems to me that you would get a very nasty pocket of dirty gas going through, until the man switches the unit on again. What are you going to do about that ? That is a point which has been raised by opponents of the superimposed electrostatic precipitator.

Mr. **T. H. Stayman** (*written reply*) : In the tube precipitator at least 160 tubes are in operation, and if one of these tubes was not working correctly a certain amount of dirty gas would go through, but I doubt if this would be any more serious than if one series of the horizontal cleaner were cut out.

Mr. **W. Banks** : It is stated in the paper that the hearth of furnace *D* has been laid in carbon blocks. Has the author any information as to the performances of furnaces laid with carbon blocks previous to that furnace *D* ?

Mr. **T. H. Stayman** : No. I asked about the carbon blocks, and was able to get very little information. I was told that furnaces had been installed with carbon-block hearths, but none had been in long enough to give any definite results. There was a paper published describing these carbon blocks, but even then I do not think that they had any final results from the furnaces actually in operation.

Major **W. R. Brown** : I am wondering whether we can draw any useful inference from the data on the first page of this paper. There we have details of three furnaces, *A*, *B*, and *C*, of approximately the same size, which were fitted with 16, 16, and 14 tuyeres, respectively. When we come to furnace *D*, we find that 20 tuyeres are provided for a furnace which has a hearth diameter of 28 ft. That means that in that furnace the tuyeres were in closer proximity than in any of the other cases. If these furnaces were built in the order given, first *A*, and then *B*, and so on, it looks as though they changed their minds at *C*, and put the tuyeres further apart, and then changed their minds again at *D* and put them even closer together than in furnaces *A* and *B*. I should like to ask whether the author has any idea of the order in which these furnaces were built or of what guided the selection of the number of tuyeres.

Mr. **T. H. Stayman** : Furnace *B* was built in 1937, and furnaces *A* and *C* in 1942.

There is one point I might mention which may be of interest to people who are concerned with bricks. I asked for the analysis of the jointing material used for the carbon blocks in the hearth, and the information may be of interest. The carbon blocks in the hearth are laid with wide joints, and a carbon paste is rammed into the voids round the blocks. The paste is made up of 50% of electrically calcined anthracite coal, 30% of graphite flour, and 20% of binder which consists of coal-tar, pitch, and tar. The calcined anthracite coal contains about 12% of ash, the remainder being carbon. The graphite flour contains about 2½% of ash. The binder material runs to 50% of volatile material and is held to less than 0·1% of water.

## Discussion on ENGINEERING PROBLEMS IN THE PREPARATION OF ORES FOR BLAST-FURNACES*

*by D. C. Hendry*

Mr. **D. C. Hendry,** introducing his paper, said : This paper is written very largely round the home ores, and particularly the Northamptonshire ores; nevertheless many of the problems mentioned are common to the foreign ore which is used so much in this country today. The plant for primary crushing can very readily be identical for both types of ore, and the feeding equipment for the crushers can also be so. The feeding of ore to the crushing plant is largely a matter of how the ore originally arrives at the plant. In the case of home-ore plants it is very easy ; with foreign-ore plants there is naturally an intermediate stage where certain reception yards must be provided, and from there the foreign ore is transferred to the crushing and grading plant and then to the furnace bins.

In this paper I have concentrated largely, as I say, on home ores, and I have endeavoured to give a chronological picture of development in regard to feeding the crushing plant itself. Fig. 1 shows the primary crushing plant at Corby which we now call the old plant, though the new one is not yet in operation. The ore is fed into the crusher by a hoisting type of tippler which has operated very well, but we feel now that we should like to have a change. From the receiving hopper the ore is fed to the scalping rolls (grizzly rolls) by a reciprocating bar feeder. This is illustrated in Fig. K, and has some obvious defects.

In Fig. 2 we have a different feeding arrangement : A drop bar feeder takes the ore from the receiving hopper and dumps it over a two-roll type of grizzly, quite a different type from that shown in Fig. 1. I have had some experience experimentally with it, and I have had the benefit of the views of people who use that type of screen, and it works very well. On the other hand it does not clean the ore sufficiently before entering the primary crusher.

I have had no particular experience of jaw crushers on ore, though I have heard a great deal about them. I pin my faith to the use of the two-roll primary, a very robust machine which stands up well in operation and deals very effectively with the tremendous lumps of ore which come its way, discharging them broken on to the conveyor equipment below.

We have experienced a great deal of damage occurring to belts receiving ore from the primary crushers at very high velocity, and we have therefore given much consideration to methods of protecting the belts below, in order to obviate costly stoppages and repairs.

Fig. 3 shows the latest development in our works for handling the ores received from the various quarries, and Fig. 4 shows the relation between the primary crushing unit and the secondary crushers. Figs. 3 and 4 fit into the scheme shown in Fig. 9. There are a number of features about this scheme which have not been brought out in the drawing, being omitted very largely for the sake of simplicity. The essential difference, starting at the beginning, is that we gravitate the ore wagons down to the wagon haul, pull them up a ramp to about the level of the crusher receiving hopper, and tipple them there. We anticipate that thereby we can get fast working, a greater wagon throughput per hour, and a slightly more robust set-up altogether. The arrangement of the sidings is shown in the diagram. They are large enough to serve a duplicate ore-crushing plant, *i.e.*, the primary and secondary ore-crushing unit would be duplicated by another unit alongside it to the right-hand side.

In our old crushing plant the secondary crushing of the ore is done with two-roll machines. We have two of them, and they work very well, except that they are probably not big enough for the tonnage and sizes of the ore now coming from the primary crusher. We have also had regard to the amount of fines which we appear to make in secondary crushing with two-roll crushers, and in the new layout we have adopted two Symons' cone crushers, which we believe will make less fines. These cone crushers are arranged to break down to about 2½ in. cube, or 3 in. at the maximum. That is the maximum which we intend to use, but it does not preclude smaller sizes being crushed, if the cone crusher is designed to give that facility. It may be desirable, particularly when foreign ores are being crushed, to crush to much smaller sizes, in which case it is a simple matter to extend the crushing plant by putting in tertiary crushers to bring the ore down to whatever size is regarded as essential. There is some indication diagrammatically on the drawing of the Salzgitter plant of tertiary crushers located at a suitable point. They do not deal with the full tonnage of ore which comes from the secondary crushers, but only with the proportion which it is desirable to bring down to a small size.

From the crushing plant we pass to our screening plant, and I should like to point out one or two things there. Fig. 7 shows, to a very small scale, the type of screens which we have adopted. The secondary crushed ore come up-hill, passes over a multi-roll grizzly, in this case for the purpose of separating oversize material which is returned to the secondary crushers. The

* *Journal of the Iron and Steel Institute*, 1947, vol. 155, Jan., pp. 121–135.

"throughs"—that is the, —2½-in. material—pass over a cascade arrangement of grooved rolls. In the set-up shown we intend to take out only —⅝-in. material, passing all the other ore to the bedding plant and thence to the furnaces. We have shown by experiment that we can effectively separate out fines as low as ⅜ in., and even as low as ¼ in., from the very wettest ores that could possibly be fed to a plant of this kind.

Although it is not shown here, we have alternative designs prepared which would permit extension of the screening plant in order to enable us to take out another fraction as well. If we wished, we could send everything above 1½ in. direct to the bedding plant. If we wanted to charge the furnace with separate layers, we could ultimately screen out in this set of grooved rolls 1½in. and below, and pass that fraction over another set of grooved rolls adapted to take out ⅜ in. We have the desirability of sintering the most uniform size of material very much in mind, and it is possible that in the future we shall put in the additional roll screens necessary to enable us to do so, by screening out the —⅜ in. ore.

In the layout shown in Fig. 9 our screened ore passes as two constituents to the bedding piles, —⅝ in. going to one pile and everything above that to other piles. From the bedding piles the material is distributed to the sinter plants or to the furnaces, whichever is the particular destination of any pile at any time.

We have had an important decision to make here. There has been some discussion this morning as to whether it is advisable to screen ore after it is crushed and before passing to the furnaces or the ore yard, or after if is put in the ore yard crushed and before passing to the furnaces. We have decided that the proper thing to do is to screen the ore before it goes into the bedding piles and therefore before it goes to the furnaces or stockyard. Screened ore from the bedding piles will be conveyed to the transfer-car bins and then to the furnace plant, and fine ore will be despatched to the sinter plants. We have in mind, however, that we might wish to bed everything that is crushed without screening, and we have provided for a certain amount of flexibility in that we can ultimately, if we wish, extract all ore which is bedded in all sizes and put it through the screening plant, separating it into about three constituents. That is readily possible, but this layout is adapted at the moment only for separating two sizes of ore. Each of the bedding piles is capable of carrying just over 9,000 tons of ore, and on present-day operation that provides an ample two-day pile of crushed ore for the furnaces. The finer ore piles, of course, carry rather more than that in terms of days' requirements for our sinter plants.

It has been suggested earlier today that to bed three constituents may very well be possible. With the layout shown in Fig. 8, which relates to Appleby-Frodingham, this might be so, but it cannot be done so readily in the layout shown in Fig. 9, for the reason that on this site we have not the room available to put in the necessary additional distributing tripper. However, even that can be done if an open site is available elsewhere and three sizes bedded. Our present site for the new bedding plant was rather restricted; it was hemmed in between the furnace ore yard and the coal sidings at the coke ovens.

For sintering we have two fairly old plants and one rather modern plant built early in the war, and we can make good sinter, but it is essential in order to do so that the materials as supplied should be properly graded. We have no coke-crushing equipment, and, although we considered the designs for it, owing to difficulties in war-time we did not go ahead with the scheme. As a matter of interest, we have carried out experiments in the screening of coke breeze with the grooved rolls for one with a very marked degree of success, and it may be that some day, in bringing breeze from our coke ovens and from outside, we shall instal a small screening plant at a suitable spot to screen out the coke of the small size which we require, passing the oversize material to domestic use. Other people think differently and instal coke-crushing plant for the sinter-plant needs. Such a coke-crushing plant is shown in Fig. 12. It is very elaborate, but it must be remembered that it was built to serve a very extensive sinter plant, and it is not out of proportion to the job which it has to do.

There are very many problems in connection with sinter plants which I am sure must be known to all those who have such plants in their works. We have at Corby two old plants which have turned out very many thousands of tons of sinter in the course of their lives, but which have given us a tremendous amount of operational difficulty and have been expensive in upkeep and repair. Our No. 3 sinter plant, the most recently built, is, we think, an improvement on the two older ones, but it still has very many defects which can possibly be rectified in the course of time, and which should be rectified very largely in the installation of new plants, of which I do not doubt that quite a number will be built in the future.

The sinter machines at Salzgitter are probably the newest of that type which I have seen, and they are very fine machines in a very fine plant. Many features of those machines, however, simply reproduce the defects which I and others have noticed in sinter plants in this country and which must have been noted, I think, in sinter plants

FIG. J—Variation in size of ore

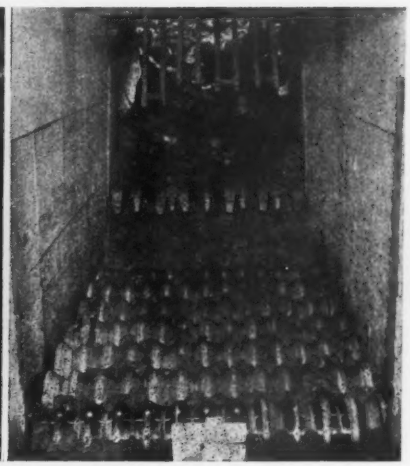


FIG. K—Feeding of ore to grizzly rolls

in the U.S.A. I feel that we must acknowledge the assistance and benefit which we have all derived from American design as applied to plant in this country, but I think that we in this country are getting down to many of these problems on our own and solving them. We are capable of solving them, and in turn we may be able to give a little "reverse lend-lease"—at a price—to the Americans. I am still of opinion that there are many things which we can show them.

There are many features of the design of auxiliary plant for blast-furnaces which do not receive the full measure of attention which they deserve. I think that we can in the future help the constructional people by giving them our considered opinions and assistance.

I do not want to describe the German ore-crushing plant in any detail. It is a tremendous plant, and one is apt to get lost in it, physically as well as mentally. In relation to the sinter plants, in the paper I mentioned (page 133) that the impellers of the sinter fans are 3 ft. 6 in. in dia. That is an error; they are 6 ft. 6 in. in dia. They are very good, but, like most sinter fans, they gave the Germans many headaches, and they were getting the same results which I have observed with our own fans.

Finally, we come to the Lurgi kilns, another plant which was magnificently laid out at a tremendous cost, and about which no doubt we in this industry will hear more in the future. That plant carries very many problems of its own. Not the least of their difficulties was to keep blast-furnace gas where it belonged, making full use of it and avoiding any dreadful explosions. These were possible in such a plant, as the German engineers fully realized, but they took very adequate steps to prevent anything of that kind occurring. There are many features of the Lurgi kilns which would interest engineers if they had an opportunity of seeing them, but it is out of the question in a paper of this kind to describe them in any detail.

I have touched on the fact that we have a sort of rudimentary system in existence for blending the various ores coming from our different quarries. The sidings are normally filled with hundreds of wagons containing ore, each siding containing ore of a different variety. The variation in size

FIG. L—View of underside of crusher rolls

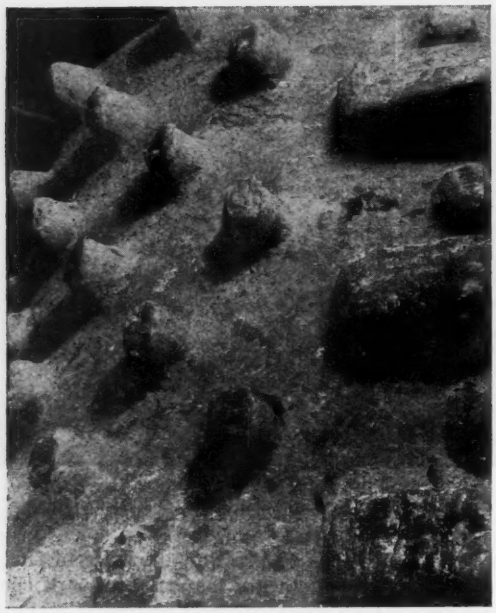


FIG. M—Welded repairs to worn slugger teeth and roll knobs

of ore can be seen by comparing different wagons. Fig. J shows the wide variation in the size of ore in an individual wagon. It is a view looking into the tippler hopper after the wagon has discharged and shows the ore being fed to the crusher. Fig. K shows ore from the hopper being fed to the grizzly rolls. This feeder has worked well, but it suffers from the fact that the bars, which move upwards and along and downwards and back are completely unsupported sideways, and, being fairly long, in the course of time become bent and leave gaps. These spaces are the cause of a great deal of damage to the belts below, and this has proved a costly type of feeder. In the new plant we have departed from it.

Fig. L is a close-up view of the underside of one of our crusher rolls, and shows how sticky the

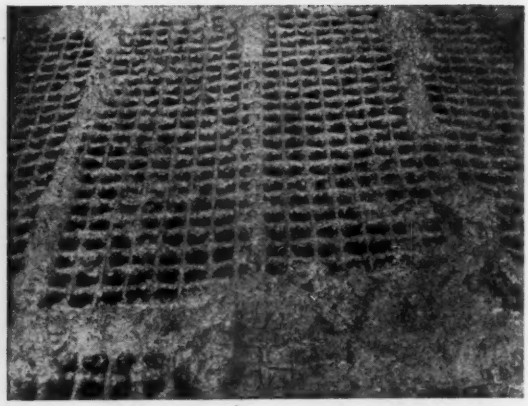


FIG. N—Example of plugging of ore screen

ore fines can be. This means that we may have to stop the crushing plant when the weather is wet, in order to get rid of the accumulation. Fig. M shows an attempt to weld-up the wear on the slugger teeth and knobs of the rolls. We are not very enthusiastic about welding under the crusher. The space is very restricted, and in the new crushing plant we are making other arrangements. Fig. N is by no means the worst example of how the ore screen can be completely plugged. With a dry ore we do not have this difficulty, but we experience it often enough with wet ore to want to get rid of it entirely.

Fig. O shows a hearth-layer machine for a sinter plant, and Fig. P shows the small roll to feed the hearth layer. One of the difficulties with this type of machine is that there are largish pieces of ore which attempt to get through the feed gate (the gate which regulates the amount deposited on the grate). These pieces jam the roll and stop the feed of this hearth layer, and of course, the inevitable happens and something breaks. We at Corby decided to eliminate that type of layering equipment and revert to the older type of swinging spout, which seemed to give an

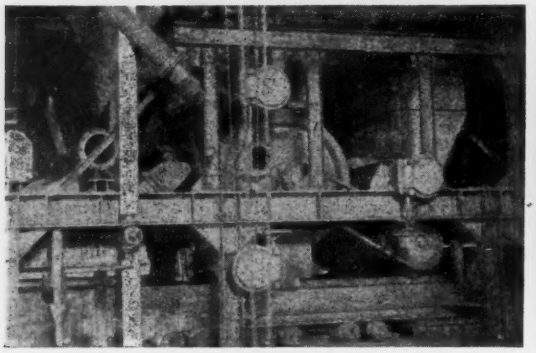


FIG. O—Hearth-layer machine for sinter plant

FIG. P—Small roll feeding the hearth layer

FIG. Q—Cast-iron pallets showing warping

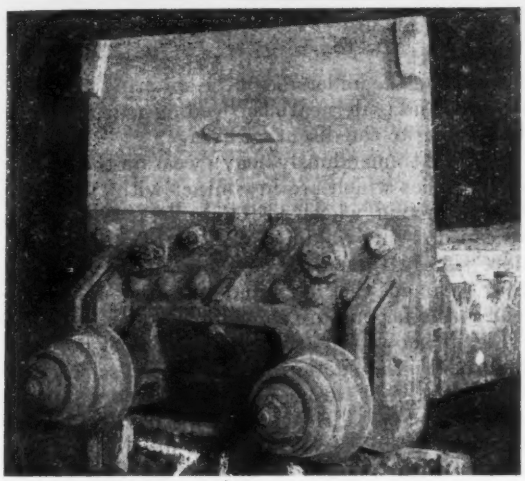


FIG. R—End view of fabricated pallet

adequate amount of segregation of coarse material to form a hearth layer.

In all our sinter plants we had as the first equipment cast-iron pallets (*see* Fig. Q). It is natural to assume that cast iron will stand up to heat, and so it does, but it has the disadvantage that it warps very badly, and this illustration shows the type of warping which takes place. This leads ultimately to breakage of the sides of the pallets and to breakage of the pallets themselves. To get over this difficulty we are steadily changing over to mild-steel fabricated pallets. The end of one of these pallets is shown in Fig. R. We can get rid of warping very easily by applying heat at the proper places to shift it. This pallet is built with heavy channel irons at each side and with a heavy I-beam down the middle. Some of the wider pallets have two I-beams.

FIG. S—Old type of pallet-bar grate

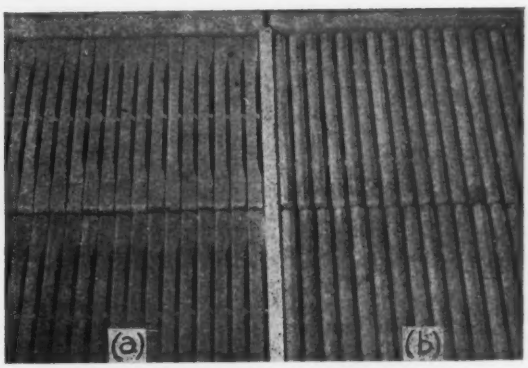



FIG. T—Comparison of old type (*a*) and new type (*b*) of grate

A type of grate which was very common and with which our plants were equipped is shown in Fig. S. The dead space which is formed by the end of the pallet bars prevents adequate suction through the porous mass which is being sintered and causes a great deal of unsintered material to lie on these dead portions. Fig. T shows a comparison between the old type of pallet bar grate and the new type which has been adopted, whereby we get continuous suction over the area of the pallet, increasing the suction area by about 20% as compared with the former type. Fig. U shows the method of carrying the pallets on their

FIG. U—Method of supporting pallets during return to the discharge area

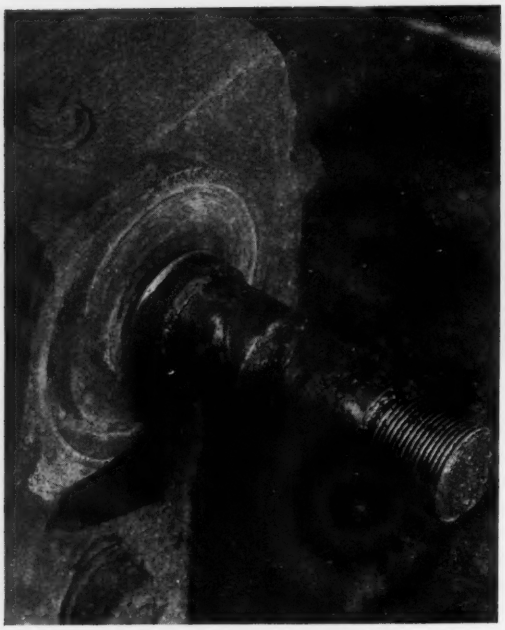


FIG. V—Pallet boss showing heavy wear

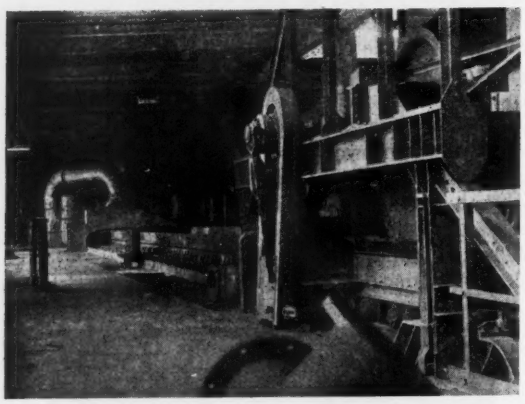


FIG. W—Hearth-layer and discharge gear

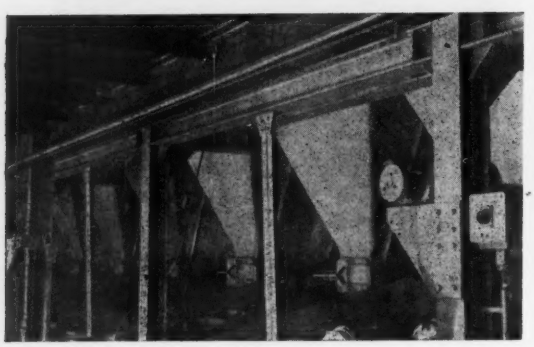


FIG. X—Arrangement of dust hoppers under suction main

FIG. Y—Jigging conveyor for screening

return from the underside of the sintering machine upwards and underneath the feeding gear, pushing them along to the discharge area.

There is tremendously heavy wear on the bosses of the pallet which are in contact with the teeth of the driving wheel (*see* Fig. V). With steel we can do some welding and get rid of the wear more simply than with cast iron. The hearth-layer gear at the near end and the discharge gear at the far end are shown in Fig. W.

Fig. X shows the arrangement of dust hoppers underneath the suction main. The discharge of dust is by hand through the small doors shown.

In the paper I touched on the inadequacy of screening of sinter. So often the sinter is allowed to drop over a grate of rails at the end of the machine. An attempt at adequate screening by utilizing a jigging conveyor is shown in Fig. Y.

## DISCUSSION

The **Chairman** : This paper fills a long-felt want, and will be on every blast-furnace engineer's designing desk for some time to come when trying to lay out ore-crushing, screening, and sintering plants. I myself have learned a great deal from this paper, and I think that that will be true of everybody who has these problems in mind to-day.

All sinter plants seem to have this trouble with fans getting eroded and out of balance and so on, and usually sinter plants get into trouble, if in a built-up area, by emitting a great deal of dust. I should like to ask whether anybody has ever built a sinter plant with an electrostatic precipitation plant between the fan and the box in order to keep down the dust erosion on the fans, and does the author think that it is possible to do that ?

Mr. **D. C. Hendry** : This question of out-of-balance sinter fans is really a serious one. The only solution, I think, is for engineers to adopt a really slow-running unit. In our No. 3 sinter plant we had very much in mind the experiences obtained with the fans in our two old plants ;

one of these fans was running at about 1,485 r.p.m. and the other, which originally ran at about 950 r.p.m., had been speeded up to 1,400 r.p.m. These fans were a nightmare, and in building the No. 3 plant we decided to come down to a reasonable speed and built the fan to operate at something like 900 r.p.m. maximum. This necessitated a fan slightly larger in diameter, but it is much steadier, and even though in the course of time it suffers erosion from impact with abrasive dusts it does not get out of hand, and the engineers have time to prepare their programme of repairs and replacements and to deal with the matter comfortably.

There are a number of ways of dealing with dust emission. I do not know of any electrostatic equipment installed at a sinter plant. I think that it would be possible to instal it. In that connection I should like to point out that there are electrostatic dust separators or precipitators at the exhaust side of the Lurgi kilns, and I see no reason why such equipment should not be incorporated in a sinter-plant layout. We had in our old plants a number of cyclones for the separation of dust. I can only say that they were not completely successful, owing very largely, I think, to the fact that as a sinter plant starts and stops the moisture in the gases condenses, and dust adheres to the "innards" of the cyclones and gradually builds up layers which have a throttling and choking effect on them, so that they do not work.

Ours did not work and so we took them out and replaced them with straight ducting liberally provided with dust hoppers beneath. This works fairly well, or at least not any worse than the old cyclones, but we still emit dust, and dust emission is still evident in our No. 3 plant in certain circumstances. We have no dust separators at all other than hoppers on the exhaust ducting, but we have provided space for the installation of dust-separating equipment of one kind or another in the future. The increasing attention which local authorities are paying to this dust nuisance, which certainly is a nuisance locally at Corby, will, I think, compel us to introduce something much more elaborate and satisfactory than we have at the present time.

Mr. **J. Vevers** (Mitchell Engineering Ltd.): As a representative of the firm which built the original ore-preparation plant at Corby, I am aware of the difficulties which the author has pointed out and which were built into the plant. It was however, the first plant of its size dealing with the class of ore mined at Corby, and we can to a large extent be satisfied with the job, which had had a very successful run.

To commence at the feed of any ore-preparation plant, it is definitely the best method to discharge wagons as close to the primary crusher as possible. Since our experience at Corby, we have much improved our designs of tipplers and tippler hoists, and, given standard wagons, from 40 to 60 wagons per hour can be dealt with quite comfortably, the bottleneck usually being the method of handling wagons to and from the discharge point. The feeder under the receiving hopper has been criticized as a screen; it is, however, very successful on some materials and has been improved since our earlier efforts. On a number of other plants with which I have been associatied, drop-bar feeders and steel-pan feeders have been used with success. A two-roll or multi-roll type of grizzley before the primary crusher is very successful in relieving the crusher of clogging from natural fines.

In this country, two-roll crushers are in the majority for primary ore crushing, but hammer mills and jaw crushers have been used. The hammer mills were not very successful at the start on Northamptonshire ore, owing to the wet and sticky nature of this material, which clogs the hammers and bars.

We have a choice of secondary crushers, and in my experience cone crushers have given most satisfaction, being adaptable to practically any class of ore.

The transport of ore from the primary to the secondary crusher by belt conveyor is probably the best and cheapest method, but the pounding which the conveyor idlers receive at the feed point from the crushers and screens has been a cause of much thought to operators and manufacturers. Single and multi-roll feeders have been used, as well as chain curtains, and a hammock belt has lengthened the life of belt and idlers at Appleby-Frodingham. It is good practice to prevent the material from dropping direct on to any idler, no matter what type is used.

With regard to cleaning the belts, scrapers are fitted, with not too much success, and this point requires attention. Certain operators have successfully fitted wire scrapers stretched across the belt, inside the chutes, but these scrapers require renewing at frequent intervals.

For fine screening, vibrating screens will deal successfully with dry ores, but on ores such as those mined at Corby they have not been fully efficient; it is noted that at Corby, on the new plant, a new type of screen is being fitted, and it will be very interesting to have more details of this in the future.

I am very grateful to the author for the information contained in the paper, and we as plant manufacturers are learning more from the operation than ever before. We have put in numbers of plants in the past, but unless we hear of the faults we cannot remedy them, and I

appreciate the opportunity of having been able to read this most interesting paper.

Mr. **D. C. Hendry** : If anything that I have said implies criticism of Mr. Vevers's firm, I hope that he will not take it as being malicious criticism ; it is intended to be helpful. Further, we at Stewarts and Lloyds do not blame his firm for defects which may have appeared or been shown up in the course of time in the operation of the plant. I should make it clear that, as Mr. Vevers says, the plant was new to us, and being a struggling firm with no money we could not afford to buy anything very much better. We are now out of that difficult position. Furthermore, the plant was laid down to feed a very much smaller plant ; our furnaces were three, and they were small ; we now have four, and they are very much bigger, and we expect they will be bigger still, so that we are taking such steps as I have outlined to improve crushing, screening, and blending, with an eye to the future as well as profiting by our experience in the past.

Mr. Vevers referred to ore tipping and standard wagons. That is a difficult point. In 1932 and earlier we had a number of small wooden wagons of about 12 tons capacity. After our plant got going we set about standardization, and we decided that 20 tons would be a nice capacity and a useful standard to adopt. We are now in the position of having between 300 and 400 of those wagons and of finding that we want to adopt another standard entirely, much bigger. While, therefore, I agree with what Mr. Vevers says, it is not going to be easy ; we must stick to some of the equipment that we have bought and adapt much of our new plant, such as tipplers, to deal with our existing wagons.

I hold no brief for any one type of feeder over another, and I am willing to have an apron feeder as compared with a drop-bar feeder, but I do not think that the reciprocating bar feeder is the best for that job.

I am fully aware of the amount of trouble which has been experienced in using jaw crushers and hammer mills for crushing the softer ores. I do not know why there should be any difficulty in crushing foreign ores, if they are not wet. The trouble with the home ores is that they are wet, and unless the fines which accompany the body of the ores are almost completely eliminated before crushing, trouble is bound to ensue. From that point of view I think that the two-roll crusher has certainly shown up very well.

I am glad to hear the support given to the cone crusher. It does not matter who makes the crusher; it is the type in which I am interested.

We have been worried a great deal about belt cleaning, and in such weather as we are having at present we have endless damage to belts owing to improper cleaning and to the build-up on the idler pulleys becoming so hard that it cuts the belts. In our new plant, however, we are adopting a new type of idler, consisting of discs mounted on a shaft, and I believe that those discs are rubber-covered.

I think that the gyratory screen is a perfectly good screen on dry ore. It may be that this experiment of ours will not be successful in dealing with the very large tonnages of ore which we must put over hourly, and we may have to revert to gyratory screens. We do not want to do so, but we may have to. We have taken precautions to be able to do so should that be necessary.

If Mr. Vevers would like to come to Corby again to enquire, as well as hastening the installation of his new plant, I shall be pleased to tell him a great deal more about the deficiencies of the old.

Mr. **H. M. Morgan** (Cargo Fleet Iron Co., Ltd.) : I have read this paper with very great interest. With reference to the scalping screens and the crusher each being able to deal with the maximum quantity being put through the plant at any one time, I suggest that this should also apply to all conveyor-belt systems. Furthermore, variable speed to whatever type of feeder is used before the primary grizzly is a very great advantage, especially where abnormal amounts of fines are likely to be found, because it does help to prevent the plugging of screens.

With regard to the damage to idlers and belts, we found it more on the idlers than in the belts, and we considered several means of overcoming it, apart from the normal chains, deflectors, and so on. We considered pneumatic-type idlers built with a series of small pneumatic tyres, vibro insulators, and rubber-covered idlers. Were rubber-covered discs adopted because that was considered to be the ideal type, or because of the high cost of the other types ?

I should like to refer to the damage which occurs to conveyor belts owing to defective skirts. The main steel skirt carrying the rubber curtain should, I feel, have an ever-increasing clearance from the belt in the direction of travel of the material. Our first belts were quickly ruined owing to material being trapped under the skirt. So far as scrapers are concerned, we have had all the troubles on jointed belts, but on our only belt which is vulcanized endless a straight steel scraper without any rubber has proved very satisfactory.

With regard to tipplers, I am pleased to note the remark that these should be good, robust tipplers. We at Cargo Fllet employ two tippler hoists, one on each side of the plant, and from the electrical and mechanical side I have very few

complaints to make; structurally they have very many weaknesses, especially the cradle beam which receives the shock of the wagon. When that is bent it alters the gauge of the wheels of the cradle, and anyone who has had a cradle with a full wagon derailed at the top of the hoist knows what that means. The rail supports and guide rail for the top wheels of the cradle should receive far more consideration.

With regard to the crushing rolls themselves, we employ twin-roll crushers for primary and secondary. Can the author give us any advice as to the type of electrodes used for welding-up the knobs, and will he say whether any particular difficulties are experienced in welding the roll shells? I agree with the author that secondary crushers of the twin-roll type produce with certain stones a very slabby and oversize product. With regard to the cone-type crusher, what would happen in the event of a navvy-bucket tooth getting through? We have experienced this on one or two occasions, and on the secondary crusher the bolts of the tie-bolt safety block shear; otherwise there is no damage.

Dust extraction is very difficult. We find trouble especially at tippler level. Perhaps the author can make some suggestions in that direction.

To pass to sinter plant, it may be of interest to mention that we are now in process of installing a rod mill to crush the breeze down to $-\frac{1}{8}$ in. We considered this necessary in order to obtain a suitable product. We have had a good deal of trouble with pallet bars in one way and another, but have come back to a straight hematite iron. This is with the rotating-pan, batch-type sinter plant. We tried a special pallet bar with a nickel-chrome content, but found that we could not justify the extra cost.

With regard to the main sinter fans, I am very surprized to read of the short life at Salzgitter. We have two of these fans, which are 6 ft. in dia. and have a speed of 1,480 r.p.m. The first rotor had to be changed after two years' life; the second rotor was changed after about three years' life, but it was out of balance before this time. We will soon be changing another rotor, which has given only 12 months' life.

Sinter screens have been one of our greatest sources of loss of output. I do not know whether the author has any particular type of screen which he would recommend, and I should like to know his opinion of the "Zimmermann" type of oscillating screen in use at Salzgitter.

I was very pleased to read the author's conclusions. If all interested parties will take heed of his advice, this paper will have been of very great service to all concerned with this type of plant.

Mr. **D. C. Hendry**: I can assure you that the capacity of all the belts in this plant has been the subject of very careful consideration, and all the belts are up to the maximum throughout the whole of the plant from the beginning to the end. They take the maximum that we are likely to be called on to take at any time; even if there were 800 tons of raw ore going up the belt per hour, the sizes and speeds have all been determined to deal with that.

Reference has been made to the advisability of having variable speed on the feeder before the grizzly rolls. I do not think that that really matters apart from start and stop. If the speed is up to the maximum tonnages which are required, it is, in my view, completely unnecessary to vary it, because the feeder is moving so slowly in any case that a variable-speed feature would not be worth the cost involved.

Rubber-covered discs were selected largely because of the difficulty of cleaning the belts, and not because of any fundamental objection to the use of a rubber-covered idler. Having made the decision, we have carried it out, and we shall go on with that practice throughout the whole of this plant.

I agree that a great deal of damage can be caused to belts by the skirt boards, but I do not know whether increased clearances are useful. If you do provide an increased clearance, you increase the chance of ore of varying sizes being trapped between the skirt and the edge of the belt and more damage being done in that way.

I am glad that Mr. Morgan has found a satisfactory scraper. I shall certainly get our engineers at Corby to try it, to see whether we have success with it also.

Mr. Morgan has referred to the difficulties in connection with the hoisting type of tippler which he has had, and they are very similar to those which we have. Not only have we had cradle beams bend, but the tippler platform has been hopelessly wrecked, and we have had to make it very much heavier, thus reducing the net useful load which we can hoist; however we get away with it at the moment.

I will ask Mr. Daniel, if he is here, to say what type of electrode we use. I know that we have tried several types.

Mr. **J. L. Daniel** (Messrs. Stewarts and Lloyds, Ltd.): We use the Murex hard-surface electrode. We used the Lincoln hard-weld before, but we found the Murex better. I do not know the chemical composition.

Mr. **D. C. Hendry**: Bucket teeth have a nasty habit of going through crushers. If you can do so you should catch them before they get through the primary crusher. We provide a man to watch the operation of the feeder and spot when digger

teeth are coming off the feeder on to the grizzly rolls. If such a piece of tramp iron were to get through the cone crusher I am not sure that it would result in serious damage, because the crusher elements are liberally equipped with springs, which would yield if a piece of iron got in, as long as it was not too big. If it were very big, I imagine that there would be trouble in any case if it were not ejected.

In considering the crushing of coke breeze for sinter plants we also had in mind the rod mill, but it may be of interest to mention that the Germans at Salzgitter used two-roll crushers, with plain rolls about 2 ft. 6 in. to 2 ft. 9 in. in dia., but I believe that they wore rather badly and I think that that would be inevitable.

We also have used all types of pallet bars in our sinter plant. I do not know of any type which we have not used. We have used drop forgings, nickel-chrome iron, and hematite iron, and we are using plain cast iron now. Plain cast iron is cheaper and lasts just as long. If we had an adequate layer equipment for the grids in the sinter plant we might be more fortunate, and I agree that the loss of sinter bars is a considerable item, particularly when the wrong size of coke gets on to them.

I have not had very much experience of the use of various types of screen on sintering, but I think that the oscillating type of screen is quite a good one, insofar as it conveys the material from one point to another and removes the fines. I should like to know more about it. They had such a thing at Salzgitter and did not seem to like it, but it was my experience over there that they did not seem to like anything. Whether that was designed to " fox " us, I do not know.

Mr. **A. Bridge**: We at Appleby-Frodingham have a fairly extensive ore-preparation plant, and can sympathize with the author in all the troubles that he has had, but there are one or two points that I want to make, and one or two questions that I want to ask. The author mentions that for the new ore-preparation plant at Corby, Fig. 3 in the paper, the arrangement is to allow for a continuous intake of 800 tons/hr. I should like to know whether this is based on the handling of wagons of 20 tons capacity, because, to be able to tip forty 20-ton wagons per hour continuously seems very good going, and if it can be done it is very encouraging.

We at Appleby-Frodingham agree with the author about two-roll crushers for primary crushing, and we have at our South Plant two two-roll crushers with rolls 6 ft. in dia., and 5 ft. in length. These have been in commission for eight years and are still in service with their original shells, having crushed between them about 17,000,000 tons of stone. At our South Plant we crush the stone for *all* our furnaces and that is the reason for the large throughput figure. The crushing knobs on the rolls are refaced every week-end, two welders working on each crusher (one on each roll), the rolls being " inched " round for access as required. We do not attempt to build up the whole of the knob by welding, but first weld on a steel pap with ordinary electrodes, and then hard-face the pap with Duroid electrodes.

The final screen shown in Fig. 7 of the paper is both novel and interesting. I feel that it is a courageous effort to solve a very difficult problem, and would welcome an opportunity of seeing it. Screening provides one of our biggest maintenance difficulties. Screen mats are in short supply, and under the severe operating conditions on a large plant they do not last very long.

As regards sintering plants, we have had troubles at Appleby-Frodingham similar to those referred to by the author. We are operating two types of sintering plant, the batch type and the continuous-belt type. The impellers on the batch type give a life of about five years, but that does not afford a true comparison with the continuous-belt type of machine, because of the difference in output; it is therefore necessary to divide this figure by four, which would bring the impeller life down to about $1\frac{1}{4}$ years. The types of sintering fan in general use still leave a lot of room for improvement, both from a maintenance and operating point of view. We have had the experience of an internal wearing plate becoming detached and getting mixed up with the revolving fan impeller. Never a dull moment!

The suction ducts on our continuous-belt machines have had to be completely rebuilt; they wore to ribbons and were patched and welded until further repairs were not practical. We have since installed new suction ducts and lined them throughout with hard facing bricks, but before doing so we put in a brick panel in one of the old ducts, and after a two years' run this brickwork was as good as new, thus proving that brick lining would save maintenance.

The main-fan casings are going now, and at the moment we are constructing two new main-fan casings in our own workshops, and it may be of interest to report that we are making them of 1-in. thick plates and *without* any wearing plates, in the hope that we shall get a life of about seven years out of them, but perhaps that is optimistic.

With reference to the sinter-discharge screens, we are trying out, on the batch plant, screens of the wedge-wire type. These have been in operation for about two years and have not yet been renewed. The screen is static, so that the maintenance is low, but we have not sufficient data as yet to say more about them. It is also

worth mentioning that on the batch plant we have a 20-in. steel-band conveyor for carrying the hot return fines. That belt was put on in 1939 and is still running, and the plant normally runs 168 hr. per week.

With regard to belt conveyors, I quite agree with previous speakers that a satisfactory belt conveyor for a jointed belt has not yet been developed. With reference to hammock belts, we had a great deal of trouble with the crushed stone from the two-roll crushers hammering the belt conveyors, thus resulting in a very short belt life, so we set to work and installed hammock belts in these regions, and where we had a belt life of 1,000,000 tons we are now getting a life of over 2,000,000 tons. We have four in operation, and they are simple, satisfactory, *and* home-made. It has always been a puzzle to us that some manufacturers go in for such complicated arrangements ; they do not seem to realize that it is simplicity we want, and in this respect we think that they ought to contact us a little more frequently and find out what our real troubles are. We have not the time to go to them with all our difficulties, and we feel that if they studied our operating problems and conditions and went away and thought about them, they would be able to do more for us in the nature of supplying trouble-free equipment.

The suggestion has been made that a plate-type conveyor could be used below an ore-wagon tippler ; well, anyone who puts a plate-type conveyor below an ore-wagon tippler deserves all that he gets.

After some eight years' experience with the drop-bar types of feeders, I can say that they are very satisfactory, and give very little trouble, but plate-type feeders for this duty are, in my opinion, out of the question.

Nobody has yet produced an ideal belt conveyor for a raw-materials plant with a view to helping us to get away from dirt and spillage. With the orthodox type of flat decking, the material gets off the belt or through the joints and piles up, with the result that idlers are fouled and prevented from turning and the plant has to be shut down while they are dug out. I wish manufacturers would consider the possibility of making a belt conveyor with a **V**-type decking, so that all spillage would fall to the sides of the conveyor and could then be shovelled back on to the belt with ease. That would save both time and labour.

Finally, we at Appleby-Frodingham *know* that a clean plant gives very little trouble ; believe it or not, 75% of maintenance troubles in ore-preparation plants are due to dirt and spillage.

**Mr. D. C. Hendry** : To deal with Mr. Bridge's last point first, I think that he and I should get into a corner, since we have very much the same view, but we might take some of the manufacturers with us !

He asks about the capacity of 800 tons/hr., and whether we intend to use 20-ton wagons. The answer is " Yes." We intend to get forty 20-ton wagons over that machine per hour if we want to do so, and if we do not do so there will be trouble for somebody, and that gentleman is here ! Normally we do not anticipate having to deal with more than about 600 tons/hr., but we are not being content with that. In the future we shall have 30-ton wagons, which will help considerably.

I am not unaware of the long life which the Appleby-Frodingham staff have been achieving from their crusher rolls with the Duroid electrode. I am very pleased that they are able to do so, and only sorry that we do not seem to be quite so fortunate. I do not know the reason for that. Generally we at Corby do weld the crusher rolls every week-end. I take the view, however, that, so far as we are concerned, the underneath part of the crusher is very inconvenient and not adapted for good welding practice, and this may lead to a certain amount of scamped workmanship. In any case, having considered that matter very carefully, we decided that in building our new two-roll crushers we would alter the design, and our ambition is to be able to take the rolls out of the new machine, drop them on the floor, and put in the two spare rolls, ready welded, any week-end that we decide it is necessary. In addition, we have developed a fairly quick method of adjusting the rolls, so that we can take-up for the wear which occurs in the course of a week or two. We do not want to continue welding underneath, though we may be driven to it.

I extend a cordial invitation to Mr. Bridge to come to see this final screen working ; I think that he will find it interesting. Some of the Appleby-Frodingham people have already seen the results of the tests which we made, and I think they saw some of the tests being made. These are really remarkable for the manner in which we can effect a clean separation of three constituents of ore.

The fan trouble at Appleby-Frodingham has not been unknown to me. In 1939 we were faced with fans which were lasting two months. At that time I drew a graph of expectation of life, and reckoned that if we did not get out of the trouble we should be stopped altogether. By getting a suitable steel—the impellers were of cast steel at that time—we felt that we could improve conditions and obtain a better life, and we did so, but we departed from the steel casting and developed, it is not a new idea, a cast-steel spider on which we riveted hard-steel plates.

Mr. Bridge mentioned the difficulty of fan

casings which wore out. We have also had that difficulty, although in our old sinter plants the casings were of cast iron lined with cast-iron plates, and we got a very good life with them and still do, except for the occasion when we also had a piece of steel plating drop on to the impeller.

We have had a similar experience with exhaust ducting. We have replaced the entire ducting on one of our plants, and a large part of it on another. Nowadays we line all our ducts with brick. We have, of course, owing to the erosion which takes place on the brick, to do patching now and again, but we are still saving the ducting. We have, however, been very unlucky with chimneys. We have rebuilt one recently, after having patched two, and it looks as though we shall have to rebuild a third, because of the corrosion which has taken place from the inside owing to the condensation of acids.

I am very interested to see that at Appleby-Frodingham they have tried a 20-in. steel-band conveyor for hot return fines. I think that that is a grand idea, and it may be that our engineers can take a leaf out of their book and do something about it.

Mr. **P. F. Grove** (Messrs. John Miles and Partners) : I should like to ask whether consideration has been given to axial-type fans for sinter plant. About the time that the No. 3 plant at Corby was put in, there was a good deal of discussion about the amount of air required for a sinter plant, and variable-speed *versus* fixed-speed drive. A reputable maker of axial fans for colliery work put up a proposition, and although this was not proceeded with at the time it seems to me that the axial fan is more aerodynamic, as is indicated by its efficiency. I agree that the present centrifugal fans are an abomination, but with the axial fan the wear should be more even with consequently less out-of-balance.

The question of the amount of air required for sintering is a little elusive, but I think the problem is one of combustion control, and either automatic $CO_2$ control or a recorder may be of some advantage in reducing the amount of excess air and so minimizing erosion of the fan parts.

Mr. **D. C. Hendry** : The difficulty in the use of an axial-flow type of fan is that the motor has to be in the stream of hot, dirty gases. I should like to hear what our electrical engineer would say if he were faced with that proposition coming from me ! Personally, I do not like it, but I would not go so far as to say that it was not feasible. I think that the blading of the axial-flow fan would receive just as much punishment as the blading of the impeller of the centrifugal type which we commonly use. It may be an advantage to use the axial-flow type of fan, but I should like to see somebody else try it first !

So far as the amount of air is concerned, I agree —and everyone with a sinter plant must agree— that there is too much excess air handled by the fan, but I am not certain that combustion control would eliminate that entirely. Combustion control might be a refinement and do some amount of good, but the leakage of air into the fan-ducting system is the real cause of the tremendous amount of excess air which we get there, and I think that most sinter-plant operators here will confirm the statement that the wear of all moving parts between the pallets and wind boxes is so tremendous that you cannot keep them tight for any length of time, even after new plant is installed. That is where the excess air comes from, in my view, but I should like to hear what other people have to say about combustion control. It may be that it could be adopted with complete success. It would obviously have to be associated with certain draught-regulating equipment installed at each wind box where the gases are extracted from the machines, and I have not yet seen a satisfactory type of control valve. I have seen quite a number taken out because of the punishment which they received.

Mr. **W. Banks** : Mr. Hendry mentions that there is a lot of bad sinter made, and I agree, because I have to use some of it ; but I do not think that we have gone quite far enough into the problem of handling the fines. For instance, I should like to know how Mr. Hendry handles his return fines. It is very easy to make a batch of bad sinter, and if the return fines have to be put back into the mixture as fast as they are being made, it simply aggravates the problem. I suggest that all screening should be done from a central hopper, so that, apart from cooling the sinter, which would help the screens, we should have more control of the return fines going back to the pan.

Mr. Hendry says that he intends premixing the fines to get a better mixture. That may be all right on Northamptonshire stone, but we use a mixture of Northampton ore, Swedish ore, soft North African ores, and also calcined French ores. With those ores we get fines which need very varying quantities of moisture to make a sinter mixture. Does Mr. Hendry think that this premixing would do away with the trouble ? We still have the fines in the mixture which require varying quantities of moisture to give a proper bed. Is it not better to crush the ores separately, keep the fines separate in the stock-yard, and mix them on to the mixer belt from separate bins ?

Mr. **D. C. Hendry** : So far as the handling of sinter fines is concerned, I have indicated in the paper that I should like to see all sinter taken away from the plant and screened, and the fines

brought back separately. At the present time on our No. 3 sinter plant there is a belt collecting dust from the suction main, as will be seen (though it does not show it very clearly) in Fig. 10. That belt takes the very fine sinter back to the plant, and it also receives such fines as are screened out at the discharge end of the machine. All this fine sinter, which is undesirable for furnace use, is returned up the sloping belt from left to right, to the mixing equipment at the charging end of the machine. I think that that is the proper place for it. I admit that it does not help to make any better sinter in our case, but with adequately prepared raw materials I think that it would not do any harm to the sinter, and I believe that it is the right thing to do.

I know that Mr. Banks' problem concerns different types of ore, but I do not see any inherent problem which is different from that at Corby, where we have two predominant types of ore but where there may be six or seven variations from the mean, and we have to mix those ore fines. Each of them carries a different amount of moisture, and I think that we have of necessity, even though some of them do carry moisture, to condition those fines together with the amounts of flue dust, etc., used with water in the mixer at the feeding equipment. I see no reason at all why sinter fines should not be bedded or mixed in any way that is considered desirable before they go to the sinter-plant stock bins. It is entirely wrong to feed separate constituents into any bins and expect to get a uniform feed out of those bins and a uniform mixture at all times. It just does not happen. With dry ores you might get away with it, but we find tremendous variations in the quality of the feed and the quantity of the feed from all our fine-ore bins at the sinter plants, and therefore I advocate putting a prepared mixture into each bin and withdrawing from the bin as and when you like and the quantities that you like, with the assurance that you are getting more or less what you want all the time.

Mr. **I. S. Scott-Maxwell**: In Fig. 7, where the author shows his final screen, it seems to me that the efficiency of screening might be somewhat critical in relation to the flow of material over the screen; that is to say, if you have a large amount of material going over the screen, might not it simply cascade down to the bottom? On the other hand, if only a small amount went over, some of the oversize might go through. This might, of course, be provided for by having variable-speed screen rolls so that adjustment could be made for different rates of feed. Has the author any comment to make on this point?

Mr. **D. C. Hendry**: Fig. 7 is not a very good diagram; it is too small. I quite agree with Mr. Scott-Maxwell. The screening is dependent on the rate of flow. Normally we shall try to even out the rate at which the screens are fed, and underneath the grizzly screen at the top of the diagram we have a very wide belt, so arranged that we can level out the stream of ore as it comes to the plant. In addition to that, we have worked out what we think should be the maximum speeds of rotation for these rolls, and have fitted a variable-speed motor to them.

Major **W. R. Brown**: I think that this paper is a most valuable contribution to the work of this Group. We have had the advantage of listening to an expert speaking on a subject of which he has very wide experience. I have one general question which I should like to put to the author. It is obvious that many people need bedding plant, but many of the more fortunate, owing to the source of their ore, do not need to have it. Where can we draw the dividing line? Can the author devise any formula or suggest any guiding principles which might be used by those who are borderline cases? That is not a question which I should expect him to answer impromptu, but if in his written reply he can suggest some general principles by which those on the borderline could be guided, and by which they would know whether bedding plant would or would not be of advantage to them, it would be very useful.

Mr. **D. C. Hendry**: I do not feel that Major Brown's very kind remarks are merited; I think that the paper is a little scrappy. I agree that there is a problem for many firms to decide whether they will go in for bedding or blending plant or not. It must be borne in mind, of course, that such a plant cannot be built without colossal expenditure. Firms will have to decide whether they are likely to benefit from so great an expenditure or not, but in these days, when the cost of coke is rising and when it is the duty of every one of us to keep down the amount of coke used, the problem is one which must be studied very closely.

I cannot lay down a dividing line, but I can give you my views for what they are worth. I think that for most plants which use a variety of foreign ores (which, although they may be chemically identical, as Mr. Scott-Maxwell says, are physically different) there is a case for a mixing plant of some kind, perhaps not so elaborate as that which I have described. I devised such a plant for use in our sinter plants. It would have been very simple, and it could be allied to any crushing and screening plant and used for feeding a blast-furnace. My own view, which may be criticized, is that there is not the slightest need to have separate-layer charging in a blast-furnace because of the reducibility aspect. All

the materials have to reach the hearth from the stockline at the same rate, if the furnaces are running uniformly ; they have to be in the hearth for a certain length of time, and they have to mix in the hearth to provide the proper slag and the iron that is necessary. I see no reason, therefore, why they should not be mixed right at the begining and go in mixed at the top of the furnace. I do not believe that you could put separate layers into any furnace with coke, as the furnace tops are built today, and keep them as separate layers more than half-way down the furnace ; I think that you get, unavoidably, interpenetration of one layer with another ; one material wants to flow more quickly than another, and there it starts.

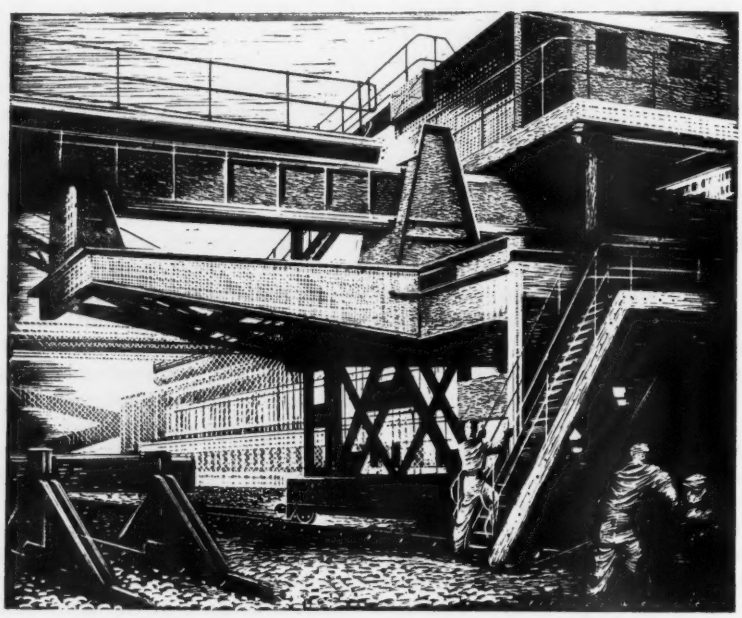
If the blast-furnace people decide that they can do without a bedding plant and are getting along nicely with the present mixing arrangements, which in many cases are somewhat crude, then that is a matter for them, but I think that most people who are running blast-furnaces nowadays should seriously consider bedding, whether they use home ore or whether they use foreign ores. It forms a very convenient way of piling-up behind you a store of material, and of allowing the stockyard to be built up with the uniform material that is wanted at all times. There are very many arguments which could be put up in favour of it, and I suppose that there are many against it, but my view is that the main difficulties are likely to be those of cost and the return to be obtained from it.

The **Chairman** : We have had a very interesting discussion, and in a way Major Brown's last question is the one which concerns us most of all, that is, " How much you can afford to put in according to your particular conditions ? " If you are already operating on a coke consumption of under 15 cwt., you probably cannot afford to put in a preparation plant in the way that you could if your consumption is much higher.

Many people in this country are at this moment thinking about the problems which we have been discussing this afternoon, namely, how to design a sinter plant which will not wear out in three months, how to build a screening plant which will not be plugged up whenever it rains, and so on. The author and other speakers have given us many ideas to work on when we get home.

Let me say one more word about this Group. It was formed, as you know, to meet a want which was felt for the practical engineer and the operator. We have to infuse into people up and down the country the desire to put their ideas on paper and send them in. I am going to propose at our next Committee meeting what should be the methods of doing that, but in the mean time I should like to tell you that half-page or page articles on engineering subjects will be very welcome. They would not be used at a meeting such as this, but would be printed in the *Journal*. You may have some small idea for a new brake or a new screen. We shall welcome such articles on practical engineering subjects and practical operating questions.

*The meeting then terminated.*



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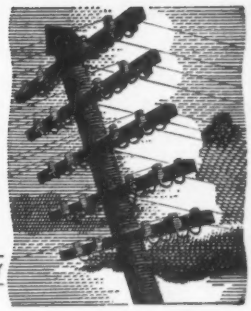

ANNOUNCEMENTS AND NEWS OF SCIENCE AND INDUSTRY

## IRON AND STEEL INSTITUTE

### Symposium on Powder Metallurgy

A Symposium on Powder Metallurgy, organized by the Iron and Steel Institute, was held in the Lecture Theatre of the Institution of Civil Engineers, Gt. George Street, London, S.W.1, on Wednesday, 18th, and Thursday, 19th June, 1947. About 150 to 200 members and visitors attended the meeting, the visitors including members of the Institute of Metals, the Institution of Mechanical Engineers, the Institution of Electrical Engineers, the Institution of Production Engineers, the Institution of Automobile Engineers, and the Society of Chemical Industry.

Twenty-eight papers, published as Special Report No. 38, were presented by the *rapporteurs*, Drs. W. D. Jones, L. Northcott, L. B. Pfeil, C. Sykes and Maurice Cook, at the three sessions, and were given a lively discussion. The Chair at the first session on Wednesday, was taken by Mr. D. A. Oliver (Director of Research, Wm. Jessop & Sons Ltd.). Col. P. G. J. Gueterbock (President of the Institute of Metals) took the Chair at the second session on Thursday morning, and Lt.-Col. Lord Dudley Gordon (President of the Institution of Mechanical Engineers) was Chairman at the last session on Thursday afternoon.

An interesting exhibition of powder metallurgy products and working materials was held in connection with the meeting.

The full report of the meeting and the discussion of papers will be published in a future issue of the *Journal*. Copies of the Special Report No. 38 "*Symposium on Powder Metallurgy*" are still available from the Secretary, price 16*s* per copy (10*s* per copy to members of the Iron and Steel Institute and the Institute of Metals).

### Luxembourg Anniversary

The Association Luxembourgeoise des Ingénieurs et Industriels celebrated the 50th anniversary of the foundation of the Association by a most successful meeting held at Luxembourg on 14th and 15th June, 1947.

A reception and concert on the evening of the first day were followed by a meeting on the Sunday in the Salle des Fêtes de l'Arbed, at which the President, M. Alphonse Wagener presided. This was followed by an official reception in the town hall, at which the Mayor welcomed members and visitors on behalf of the municipality. His Royal Highness the Prince of Luxembourg presided at the luncheon in the casino which followed, and during this, official addresses were presented by representatives of many kindred organizations in Belgium and other countries.

The Iron and Steel Institute was represented by the President, Dr. C. H. Desch, F.R.S., and the Secretary, Mr. K. Headlam-Morley. Dr. Desch presented to the Association a copy of H. C. Hoover's translation (1912 edition) of the *De Re Metallica* by Georgius Agricola, first published in Latin in 1556.

### Bessemer Medal

The Council of the Iron and Steel Institute has decided to award a Bessemer Gold Medal to Dr. h.c. Magnus Tigerschiöld, in recognition of his distinguished services to the Swedish Iron and Steel Industries. The award is made on the occasion of the 200th anniversary celebrations in September, 1947, of the foundation of Jernkontoret, of which Dr. Tigerschiöld is Chief Engineer. A further notice will be published next month.

## Staff Biography No. 7

GLADYS DAVISON was born and educated in London. After a business training at a Secretarial College she joined the staff of the Iron and Steel Institute in 1918, at the close of the First World War, and there obtained an experience of administrative duties first in the Correspondence Office and then in the Accounts Department. In 1925 she was transferred to the Library and Information Department, being the first lady assistant to work in the Library. During her long association with the Library she has rendered valuable service, and her considerable experience has played no small part in developing the service to Members. She is responsible for the preparation of *Additions to the Library*, a quarterly pamphlet by which Members are kept informed of recent acquisitions to the collection of books. In addition to her routine Library duties she has been called upon to assist the Librarian in the compilation of indexes for the *Journal*, including the last two published decennial indexes. She has also assisted in the organization of Autumn Meetings, Banquets and other social functions, held by the Institute. During the recent war years, when the Library staff was depleted owing to the demands of the Services, much of the burden of maintaining the efficiency of the Library, under trying conditions, fell upon her shoulders. She is well known to the Members and has made many friends during her long service on the Staff.

## NEWS OF MEMBERS

▶ Mr. V. H. LAWRENCE has been made a Vice-President of the Jones and Laughlin Steel Corporation, Pittsburgh, Pa., U.S.A.

▶ Mr. F. F. GORDON has been appointed Managing Director of Messrs. Spear and Jackson, Ltd., Sheffield.

▶ Dr. D. W. DAVISON is shortly leaving the physics staff of the Brown-Firth Research Laboratories to take up the position of C.S.I.R. Senior Research Officer, Research School of Metallurgy, University of Melbourne, Australia.

▶ Mr. LOUIS J. ROHL has been appointed Assistant Chief Metallurgical Engineer of the Carnegie-Illinois Steel Corporation, Pittsburgh, Pa., U.S.A.

▶ Mr. THOMAS WILLIAMS is now with the Anglo-Iranian Oil Co., Ltd., Abadan, South Iran.

▶ Mr. J. F. MILLS is joining the Design and Research Centre at the Goldsmith's Hall, London.

▶ Mr. E. H. F. STONE is returning to the Witton Research Department of Imperial Chemical Industries, Ltd. (Metals Division), after five and a half years at the Swansea Works of the Company.

▶ Mr. D. G. BOXALL has left the Parson and Marine Engineering Research and Development Association to take up an appointment as metallurgist to the Gas Turbine Division of A. V. Roe (Canada), Ltd.

▶ Mr. A. RAMSAY MOON is resigning his position as Director of the British Welding Research Association.

▶ Mr. R. F. MCGAVIN has joined the staff of the Panteg Works of Messrs. Richard Thomas and Baldwins, Ltd., as research metallurgist and head of the research section.

▶ Mr. W. GLASS has been appointed Joint Managing Director of Messrs. Johnson and Phillips, Ltd., London.

▶ Mr. W. B. PARKER has now retired from the staff of the Research Laboratory of the British Thomson-Houston Co., Ltd.

▶ Mr. ERIC SHAW has been appointed a Director of the Oughtbridge Silica Firebrick Co., Ltd.

▶ Mr. W. FREEMAN HORN has retired from the positions of Intelligence Officer and Manager of the Special Products Department, British Aluminium Co., Ltd.

▶ Dr. N. D. CHOPRA DE RAHON has been appointed Chairman of Darwins, Ltd., Sheffield.

### Elections

▶ Lord RIVERDALE has been elected President of the British Council.

▶ Mr. J. WOODMAN has been elected to the Council of the Production Engineering Research Association.

▶ Dr. C. H. DESCH, F.R.S., has been elected a corresponding member of the French Academie des Sciences.

▶ LORD MCGOWAN has been elected President of the British Standards Institution.

### Awards

The President and Members of Council offer their congratulations to the following Members:

▶ Dr. ANDREW MCCANCE, who has been made Knight Bachelor, Dr. T. P. COLCLOUGH, who has been awarded the C.B.E., and Mr. R. S. BROWN, who has received the M.B.E., in the Birthday Honours.

▶ Col. P. G. J. GUETERBOCK, who has been appointed an A.D.C. (additional) to H.M. The King.

## Obituary

The Council regret to record the deaths of:

Mr. J. E. WOTTON, of Messrs. Partridge, Jones and John Paton, Ltd.

Mr. J. F. JOBSON, American Representative of the Broken Hill Proprietary Company, Limited, Australia.

Mr. ANDREW MCQUISTAN, Director and General Manager, South Durham Iron and Steel Co., and the Cargo Fleet Iron and Steel Co.

Mr. W. BUCHANAN, Vice-Chairman and Managing Director of Messrs. Pease and Partners, Ltd., Darlington.

Mr. F. W. COOPER, formerly Managing Director of the Partington Steel and Iron Co., Ltd.

Mr. PERCY F. CLARKE, formerly General Works Manager, Cargo Fleet Iron Co., Ltd.

## EDUCATION

### National Certificates in Metallurgy

A list of Educational Bodies and Colleges providing facilities for study, leading to National Certificates in Metallurgy, was published on page 143 of the January issue of the *Journal*. Schemes submitted by seven additional Technical Colleges have now been approved, and the full list of Technical Colleges is now as follows:

Ordinary Certificates—

*Battersea Polytechnic, London; Birmingham Central Technical College; Chesterfield, Coventry, Cumberland (Workington), Enfield, Merchant Venturers' (Bristol), Constantine (Middlesbrough), Newport, Rotherham, Scunthorpe, and Swansea Technical Colleges; Dudley and Staffordshire Technical College* (Scheme supplementary to the Scheme of County Technical College, Wednesbury); *Rutherford College of Technology, Newcastle; The Chance Technical College, Smethwick; Wednesbury County Technical College and the Wolverhampton and Staffordshire Technical College.*

Higher Certificate—

*Chesterfield Technical College; Wednesbury County Technical College and the Wolverhampton and Staffordshire Technical College.*

### Stanton Ironworks Training Centre

With the object of providing convenient opportunities for study for apprentices and others, the Stanton Ironworks Company, Limited, have established a fully equipped Training Centre comprised of Foundry, Engineering and Woodwork Departments, each under the supervision of full-time instructors, who have had a wide industrial experience.

The Foundry Training Section of the Centre is a complete foundry unit, containing equipment designed to demonstrate the fundamental principles of good foundry practice.

For theoretical training the Centre is equipped with classrooms fitted with visual instruction aids, a cinema, and a technical reference library.

## CONTRIBUTORS TO THE JOURNAL

**Hugh Ford, Ph.D.**—Director of the Paterson Engineering Company, London. Dr. Ford received a public school education, followed by a premium apprenticeship at the Great Western Railway Locomotive Works, Swindon. Whilst studying for a London University External Degree he obtained a three-year Whitworth Scholarship, in 1934. After further study at the City and Guilds College he obtained, in 1936, a 1st Class Honours degree in Mechanical Engineering, and was awarded an Unwin Scholarship. He received a Ph.D. degree after three years' research in heat transfer and fluid flow problems, the results of this work being published by the Institute as a paper on "*Heat Transfer in the Flow of Gas through a Bed of Solid Particles.*"

In 1939 Dr. Ford joined the Alkali Division of Imperial Chemical Industries, Ltd., as a research and development engineer leaving, in 1942, to take up the position of Chief Engineering Officer with the Technical Department of the British Iron and Steel Federation. In this position he was responsible for the installation of new equipment for the Experimental Rolling Mill at the University of Sheffield.

With the formation of the British Iron and Steel Research Association, in 1945, Dr. Ford became the Head of the Mechanical Working Division and as such he has been largely concerned in the setting up of the Coatings Laboratory at Sketty Hall, Swansea. He left the Association a few months ago to take up his present appointment.

**Martin L. Hughes, M.Sc., F.I.C.**—Head of Metallurgy Section, Swansea Laboratories, British Iron and Steel Research Association.

**Charles Sykes, D.Sc., F.R.S.**—Director of the Brown-Firth Research Laboratories, Sheffield.

[Biographical notes of Mr. Hughes and Dr. Sykes were given on pages 125, (May) and 303, (June) of the *Journal*.]

## IRON AND STEEL ENGINEERS GROUP

The **Fourth Meeting** of the Iron and Steel Engineers Group was held on Wednesday, 11th June, 1947, at 4, Grosvenor Gardens, London, S.W.1.

Dr. C. H. Desch, F.R.S., President of the Iron and Steel Institute, took the Chair during the morning session, which was devoted to the discussion of a paper, "*Steam Turbines for Iron and Steel Works*," presented by Mr. I. V. Robinson, and a paper, "*Water-Tube Boilers for Iron and Steel Works*," presented by Mr. A. S. Peacock on behalf of the Water-Tube Boilermakers' Association.

Major W. R. Brown was Chairman during the afternoon session, when Dr. A. T. Bowden, Mr. W. H. Gibson, Mr. J. W. Railly and Mr. R. G. Voysey presented for discussion the four parts of their joint paper entitled "*Gas Turbine Applications in Iron and Steel Works*."

About one hundred members attended the discussions and a Buffet Luncheon was held in the Library during the meeting.

The discussion of the papers, which were published on pages 81–118 of the May issue of the *Journal*, will be published, if possible, in the September issue of the *Journal*.

## THE BRITISH IRON AND STEEL RESEARCH ASSOCIATION

### The Engineer and Blast-Furnace Problems

The major engineering task before the Industry at the present time is to raise the standard of all blast-furnaces to the level set by the most modern furnace installations, and this is principally to be achieved by the reconstruction of the older works.

Future improvements in the engineering of blast-furnace plant goes beyond this target, and the British Iron and Steel Research Association is now engaged on a study of various engineering problems arising from proposed new methods of blast-furnace operation.

One aspect of this development, which has reached the stage of detailed practical study, is the adoption of the compensated charging systems advanced by Dr. H. L. Saunders, Head of the B.I.S.R.A. Iron Making Division.

A Committee is being set up by the Plant Engineering Division of B.I.S.R.A. to study this particular problem in detail, from the engineering point of view, as well as other possible advances in engineering technique as applied to blast-furnace plant. This Committee will work in consultation with some of the principal plant manufacturers.

Among the various problems which may also be considered is the possibility of measuring external stresses of furnace structure and relating the measurements to the internal conditions of the furnace.

### Corrosion Research

At the present time some £12,000 is being spent each year on anti-corrosion researches under the British Iron and Steel Research Association's supervision. These cover investigations from the Arctic Circle to the tropics, and subjects ranging from the fouling of ships' bottoms to atmospheric corrosion in Khartoum.

Dr. J. C. Hudson, who is in charge of the Association's Corrosion Laboratory at Birmingham, described some of the work of the Laboratory in an address to the *Association Belge pour l'Etude, l'Essai et l'Emploi des Materiaux*, on 18th June, 1947. This work was initiated by the Iron and Steel Institute in 1928, and Dr. Hudson has been actively associated with it since the following year.

Dr. Hudson's address will form the basis of a paper that he will present at the Conference on Corrosion, to be held in Paris next October.

### Joint Conference at Ashorne Hill

The joint Iron Making Division and British Coke Research Association Conference, held at Ashorne Hill on 8th May, was well attended by both blast-furnace and coke-oven managers.

A draft specification for blast-furnace coke, which had been prepared by the Blast-Furnace Practice Committee, was favourably received, and after discussion it was agreed that the specification should be examined further by the newly formed Joint Coke Committee.

### Staff Appointments

Mr. D. FINCH has joined the Iron Making Division as Assistant Technical Secretary.

Mr. G. WITHERS has been transferred to the Chemistry Department from the Metallurgy Division. This follows the transference of responsibility for the technical direction of corrosion researches to the Chemistry Department, as Mr. Withers is the Technical Secretary to the Corrosion Committee and Sub-Committees.

Mr. G. M. LEAK has joined the Metallurgy Division as Assistant Technical Secretary.

Mr. D. J. BISHOP has been appointed Head of the Operational Research Section in place of Mr. Pearcy, who has resigned.

Dr. A. V. BRANCKER has joined the Plant Engineering Division as Senior Assistant Fuel Technologist.

## INSTITUTION OF METALLURGISTS

The **Third Annual General Meeting** held on Thursday, 12th June, 1947, at 4, Grosvenor Gardens, London, S.W.1, was well attended.

After the transaction of formal business, the President, Dr. J. W. Jenkin, gave a short address, which was followed by a vigorous and useful discussion on the activities of the Institution. The proceedings concluded with a tea and conversazione.

The new list of Council and Officers is as follows :

**President**

J. W. JENKIN, Ph.D.

**Past-President**

H. MOORE, C.B.E., D.Sc.

**Vice-Presidents**

G. L. BAILEY, M.Sc.
MAURICE COOK, D.Sc.
Sir WILLIAM GRIFFITHS, D.Sc.
R. A. HACKING, O.B.E., M.Sc.
R. MATHER, B.Met.
F. C. THOMPSON, D. Met.

**Honorary Treasurer**

C. J. SMITHELLS, M.C., D.Sc.

**Ordinary Members of Council Representing the Fellows**

W. E. BARDGETT, M.Sc.
L. E. BENSON, M.Sc.
E. W. COLBECK
E. GREGORY, Ph.D.
J. E. HURST, D.Met.
W. HUME-ROTHERY, D.Sc., F.R.S.
N. P. INGLIS, Ph.D.
A. J. MURPHY, M.Sc.
W. W. STEVENSON, A.Met.

**Ordinary Members of Council Representing the Associates**

W. E. BALLARD
W. BARR
R. GRIFFITHS, M.Sc.
C. E. HOMER, Ph.D.
W. K. B. MARSHALL, B.Eng.
H. O'NEILL, D.Sc.

**Nominated by the Iron and Steel Institute**

H. H. BURTON
J. SINCLAIR KERR

**Nominated by the Institute of Metals**

Col. P. G. J. GUETERBOCK, C.B., D.S.O., M.C.
J. L. HAUGHTON, D.Sc.

## ASSOCIATION OF ENGINEERS, LIÉGE

### Centenary, 1947

The Centenary of the Association of Engineers graduated from the University of Liége, is to be celebrated with an International Exhibition of Scientific Research and Industrial Control. The Exhibition will take place in August and September, 1947, in the University Institutes of Val-Benoît. The aim of the Exhibition, which is receiving full Government recognition and support, is to show to technicians, engineers and manufacturers the facilities for industrial control made available by scientific and technical developments, and to emphasize the necessity for close relationship between Universities and the Industry.

In addition to the exhibits of the University Institutes there will be private stands covering Metal Control, Physical Metallurgy and Ore Testing amongst many other aspects of Civil, Mechanical, Electrical and Chemical Engineering and Science.

Additional details of the Exhibition will be published in the *Journal* at a later date, but further information may be obtained direct from the organizers—Association des Ingénieurs Sortis de l'Ecole de Liége, 12, Quai Paul van Hoegaerden, 12, Liége, Belgium.

## ENGINEERING AND MARINE EXHIBITION

In connection with the Exhibition, brief details of which were given on page 626 of the April issue of the *Journal*, an official visit of the Council and Officers of the Iron and Steel Institute is being arranged, and will take place on 12th September, 1947.

Members are reminded that requests for complimentary tickets, for entry to the Exhibition, should be made to the Secretary as soon as possible.

## DIARY

**28–31, July**
SOCIETY OF CHEMICAL INDUSTRY—Annual General Meeting, Connaught Rooms, London, W.C.

**28–31, July**
POLYTECHNIC, LONDON—Summer School on Rheology.

**2, Aug.–28, Sept.**
ASSOCIATION OF ENGINEERS, LIÉGE—International Exhibition of Scientific Research and Industrial Control.

**28, Aug.–13, Sept.**
Engineering and Marine Exhibition, Olympia, London.

**1, Sept.**
MOND NICKEL FELLOWSHIPS — Completed application forms should reach the Secretary of the Committee.

**1–12, Sept.**
UNIVERSITY OF CAMBRIDGE—Summer School in Metal Physics, Cavendish Laboratory.

**2–9, Sept.**
World Power Conference : Fuel Economy Conference, The Hague.

**5–7, Sept.**
INSTITUTION OF METALLURGISTS—Refresher Course, *Transformations in Solid Metals*, L.M.S. School of Transport, Derby.

## TRANSLATION SERVICE

Since the announcement made in the June issue of the *Journal* (*see* page 306), further translations have been put in hand and the following are now available or in course of preparation :

### TRANSLATIONS AVAILABLE

No. 310 (German). E. COTEL : " The Development of the Blast-Furnace Profile." (*Royal Hungarian Palatine-Joseph University, Publications of the Department of Mining and Metallurgy*, 1941, vol. 13, pp. 3–10).

No. 311 (German). A. GELEJI : " Power Requirements for Rolling and for Mill Trains." (*Royal Hungarian Palatine-Joseph University, Publications of the Department of Mining and Metallurgy*, 1940, vol. 12, pp. 192–212).

No. 312 (Russian). M. A. SHAPOVALOV : " Performance of a Blast-Furnace with Oxygen-Enriched Blast." (*Kislorod*, 1944, No. 1, pp. 17–31).

No. 313 (Russian). A. A. BOCHVAR and V. V. KUZINA : " Influence of the Character of Crystallization and the Period of Crystallization on the Mobility of Molten Metal between Growing Crystals." (*Bulletin de l'Académie des Sciences de l'URSS, Classe des Sciences Techniques*, 1946, No. 10, pp. 1459–1462).

No. 314 (German). E. LANZENDÖRFER : " Influence of Cast-Iron Chills on the Density and Strength of Bessemer Steel Castings." (*Giesserei*, 1939, vol. 19, May 13, pp. 181–86).

### TRANSLATIONS IN COURSE OF PREPARATION

(German). G. BULLE : " The Production of Pig Iron with Low-Iron Burdens." (*Stahl und Eisen*, 1947, vol. 66–67, Mar. 27, 69–78).

German). A. GELEJI : " The Theoretical Problems Involved in the Design of Rolling-Mill Stands." (*Royal Hungarian Palatine-Joseph University, Publications of the Department of Mining and Metallurgy*, 1941, vol. 13, pp. 224–242).

(German). A. GELEJI : " Calculating the Forces Arising and the Power Requirements in the Mannesmann Tube-Rolling Process." (*Royal Hungarian Palatine-Joseph University, Publications of the Department of Mining and Metallurgy*, 1941, vol. 13, pp. 208–223).

(Russian). M. A. GLINKOV and V. C. KOTCHO : " On the Question of Heat Transfer in a Molten Bath by Gas Bubbles." (*Bulletin de l'Académie des Sciences de l'URSS, Classes des Sciences Techniques*, 1946, No. 10, pp. 1463–72).

(Russian). A. C. HEINMAN : " Molecular Constitution of Open-Hearth Slags and the Distribution of Oxygen and Sulphur in the Slag-Metal System." (*Bulletin de l'Académie des Sciences de l'URSS, Classe des Sciences Techniques*, 1946, No. 10, pp. 1439–58).

(Russian). V. V. KONDAKOV : " Steel-Melting Trials with Oxygen-Enriched Blast in the Bessemer Converter at the Stalin Kuznetk Metallurgical Combine." (*Bulletin de l'Académie des Sciences de l'URSS, Classes des Sciences Techniques*, 1946, No. 10, pp. 1401–20).

(German). F. KÖRBER and W. OELSEN : " The Action of Carbon as a Reducing Agent in the Reactions of the Steelmaking Processes with Acid Slags." (*Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung*, 1935, vol. 17, No. 4 pp. 39–61).

(German). K. RUMMEL : " The Gas Balance in Iron and Steel Works." (*Stahl und Eisen*, 1947, vol. 66–67, Jan. 2, pp. 19–23).

(Swedish). E. SUNSTRÖM : " The Development of the Electric Steel Furnace during the World War 1939–45." (*Jernkontorets Annaler*, 1946, vol. 130, No. 10, pp. 477–549).

(Russian). F. F. VITMAN, N. N. DAVIDENKOV and N. A. ZLATIN : " Cold-Brittleness of Steel in Torsion." (*Journal of Experimental and Theoretical Physics, U.S.S.R.*, 1940, vol. 10, Nos. 9–10, pp. 1137–45).

(Russian). Ya. B. ZELDOVICH and N. N. SEMENOV : " Kinetics of Chemical Reactions in Flames." (*Journal of Experimental and Theoretical Physics, U.S.S.R.*, 1940, vol. 10, No. 9–10, pp. 1116–1136).

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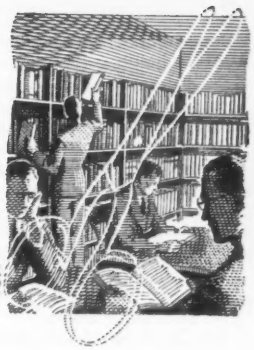
# ABSTRACTS OF CURRENT LITERATURE *and* BOOK NOTICES



IRON AND STEEL MANUFACTURE AND RELATED SUBJECTS

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## MINERAL RESOURCES

**Results of Magnetometric Survey at Benallt Manganese Mine, Rhiw, Caernarvonshire.** A. W. Groves. (Bulletin of the Institution of Mining and Metallurgy, Mar., 1947, No. 484). The results are presented of a magnetic survey carried out to determine the extent of the manganese ore bodies in this district.—R. E.

**The West Coast Haematite Bodies.** G. A. Schnellmann. (Mining Magazine, 1947, vol. 56, Mar., pp. 137–151). This is a discussion of the nature, origin, field relationships and exploration of hematite ore deposits which occur in the carboniferous limestone adjacent to the coats of Cumberland and North Lancashire. Production of high-grade non-phosphoric iron ore from this area has passed its zenith and has for many years been on the decline. A consideration of the nature and geological relationships of the ore bodies, however, leads to the belief that the prospects of a revival are excellent, but they are conditional on a scientific approach to the ore-finding problem.—R. E.

**Iron Ore Reserves of the Mesabi Range.** E. W. Davis. (Iron and Steel Engineer, 1947, vol. 24, Feb., pp. 75–79). The geological formation of the iron ores of the Mesabi range are described, estimates of the reserves are made, and the possibilities of obtaining a concentrate from the taconite are considered.—R. A. R.

**The Story of Mina Ragra. Premier Vanadium Find.** D. F. Hewett. (Engineering and Mining Journal, 1947, vol. 148, Jan., pp. 59–63). The discovery and early development of the vanadium deposits at Mina Ragra, Peru, are described. Since 1907 this mine has been the world's principal source of vanadium.—R. E.

## ORES—MINING AND TREATMENT

**Mining of Iron Ore by Underground and Opencast Methods.** (British Intelligence Objectives Sub-Committee, 1947, Final Report No. 1158: H. M. Stationery Office). An account is given of the techniques and equipment used in working iron ore in mines and quarries in the Salzgitter-Ilsede and Minden areas of Germany. Information is presented on the beneficiation of ores and the geology of the ore deposits.—C. O.

**German Brown Coal Industry.** (British Intelligence Objectives Sub-Committee, 1947, Final Report No. 734: H. M. Stationery Office). The methods employed in Germany for opencast work are described with a view to ascertaining if any of them would be applicable to British conditions—R. A. R.

**Some Experiments with Tungsten Carbide Tipped Drill Steel.** J. H. Bloemsma, R. Ramsay, and O. Deane. (Journal of the Chemical, Metallurgical and Mining Society of South Africa, 1947, vol. 47, Jan., pp. 243–275). A report is presented on an extensive investigation of the efficiency of rock-drilling in South Africa, with drills tipped with tungsten carbide.—R. A. R.

**Drilling with Steel and Hard-Metal Drills with Different Types of Rock-Drilling Machines.** C. O. Didring and S. Åberg. (Teknisk Tidskrift, 1947, vol. 77, Apr. 12, pp. 359–363). (In Swedish). A detailed account is given of an investigation of the efficiencies of several types of Atlas Diesel rock-drilling machines. The rates of drilling with steel and with hard-metal drills were compared and the air pressures were noted. The holes were drilled horizontally to a depth of 2.2 m. The results indicated that, in general, faster drilling was obtained with the hard-metal drills, that one type of machine delivered too heavy a blow for hard-metal drills, and that some types of machine were more easily moved to a new position than others—R. A. R.

**Iron Ore Review for 1946.** M. D. Harbaugh. (Blast Furnace and Steel Plant, 1947, vol. 35, Jan., pp. 60–67). Detailed statistics of American iron ore production, shipments, and consumption are given, and some recent developments in ore mining and preparation are mentioned.—J. R.

**Conditioning of Alabama Iron Ores.** A. A. Nilsen and R. Yingling. (Steel, 1947, vol. 120, Mar. 31, pp. 110–118). A description of the large ore-crushing and sintering plant of the Tennessee Coal, Iron and Railroad Co., Birmingham, Alabama, is given.—R. A. R.

**Good Sinter and Its Production.** T. W. Plante. (Eastern States Blast Furnace and Coke Association, and the Blast Furnace and Coke Association of the Chicago District: Blast Furnace and Steel Plant, 1946, vol. 34, Dec., pp. 1515–1519; vol. 35, Jan., pp. 100, 114, 116–117). The results of tests on the reducibility of magnetite concentrates, and hard and soft magnetite and hematite sinters are presented, and sinter-plant equipment and practice are discussed.—J. R.

**The Dressing of Iron Ores.** F. B. Mitchell. (Mine and Quarry Engineering, 1947, vol. 13, Feb., pp. 45–53). The author discusses methods of treating iron ore and gives flow-sheets of plants for washing, float-and-sink treatments, magnetic roasting, and magnetic concentration.—R. E.

**Research Widens Field for Iron-Ore Beneficiation.** G. J. Holt. (Engineering and Mining Journal, 1947, vol. 148, Feb., pp. 108–111). Developments in iron-ore concentration in the Lake Superior district during 1946 are reviewed. Much research is being directed to the problem of concentrating fine ore.—R. E.

## BLAST-FURNACE PRACTICE AND THE PRODUCTION OF PIG IRON

**Argentine Iron Mines and Blast-Furnace.** (Engineer, 1947, vol. 183, Mar. 21, pp. 237–238). This is an abridged translation of a report prepared by the General Directorate of Military Factories in the Argentine Republic; it describes the charcoal blast-furnace and auxiliary plant at Palpala, where the first pig of Argentine cast iron was produced in October, 1945.—R. A. R.

**Some Questions on Interrelated Processes Going on in the Blast Furnace.** B. M. Larsen. (American Institute of Mining and Metallurgical Engineers, Technical Publication, No. 2132: Metals Technology, 1947, vol. 14, Feb.). In discussing the physical chemistry of the blast-furnace process the author lists a number of questions upon which information is lacking or not readily available.—C. O.

**Thermal Requirements for Blast Furnace Operation.** C. E. Agnew. (Steel, 1947, vol. 120, Mar. 3, pp. 130–132, 166–168; Mar. 10, pp. 106–112; Mar. 17, pp. 120–126; Mar. 24, pp. 104–107). In the first part of this series of articles a comparison is made of blast-furnace practice using burdens peculiar to the Eastern, Southern, and Northern districts of the United States. The second part deals with the manner in which the thermal conditions in the blast-furnace affect the production of flue dust. A calculation is also made of the heat consumed in the reduction of iron silicate. In the third part the operating data for the practices in the three districts are critically analysed. In the concluding part the effect of using oxygen-enriched blast in the three districts is considered.—R. A. R.

**Blast Furnace Vitamins—Carbon, Oxygen and Pressure.** O. R. Rice. (Blast Furnace and Steel Plant, 1947, vol. 35, Jan., pp. 89–91). Carbon linings, oxygen-enriched blast, and operating blast-furnaces at high blast-pressure are discussed.—J. R.

**Renewed Interest in Oxygen-Enriched Blast.** W. A. Haven. (Blast Furnace and Steel Plant, 1947, vol. 35, Jan., pp. 95–96). The benefits to be expected from the use of oxygen-enriched air for blast-furnaces have been proved by experiments, but the potential economies are determined by the availability and cost of oxygen. It is expected that a project, now in its engineering and construction stages, which utilizes improved processes and equipment, will make possible the production of oxygen in large quantities at a greatly reduced cost.—J. R.

**Advances in Industry and Science in 1946.** E. Velander. (Teknisk Tidskrift, 1947, vol. 77, Feb. 1, pp. 97–109). (In Swedish). This review of scientific and industrial achievements covers a wide range of subjects. Under the heading "Oxygen" (contributed by Kalling) it is stated that a Canadian steelworks is adding oxygen to the fuel for open-hearth furnaces in order to shorten the refining time. At the Republic Steel Corporation a blast-furnace has been modified to operate at a pressure of 2·5 atm. at the tuyere level; this reduces considerably the velocity of the gases in the furnace and the quantity of dust carried over and makes it possible to increase the blast and thus increase production.—R. A. R.

**Blowing-Out a Blast-Furnace.** R. Fowler. (Journal of the Iron and Steel Institute, 1947, vol. 155, Apr., pp. 513–520). General considerations in blowing-out a blast-furnace are discussed and blowing-out procedures are reviewed. The method adopted at the Ebbw Vale plant of Messrs. Richard Thomas and Baldwins Ltd., and a particular blowing-out operation at these works are described. In an appendix J. W. Houghton describes the blowing-out of a furnace at the works of The Park Gate Iron and Steel Co., Ltd.—R. A. R.

**Pig-Iron Production from Lean Burdens.** G. Bulle. (Stahl und Eisen, 1947, vol. 66–67, Feb. 27, pp. 69–78). The manner in which the costs of producing pig iron are affected by a reduction in the iron content of the burden is carefully analysed and discussed.—R. A. R.

**Measuring Stick for the Life of a Blast Furnace Lining.** F. E. King. (Blast Furnace and Steel Plant, 1947, vol. 35, Feb., pp. 215–216). A survey of the campaigns of 32 blast-furnaces of various sizes indicated that a reasonable expectation of lining life was 2500 operational days. Examples of the use of such a figure in the drawing-up of a relining programme are given.—J. R.

**Production of High Alumina Slags in Blast Furnaces and Allied Processes for Recovering Alumina.** (British Intelligence Objectives Sub-Committee, 1946, F.I.A.T. Final Report No. 927: H. M. Stationery Office). —R. A. R.

## PRODUCTION OF STEEL

**Recent Developments in Steel Making.** J. A. Kilby and W. G. Cameron. (Institution of Engineers and Shipbuilders in Scotland, February, 1947, Preprint; Metallurgia, 1947, vol. 35, Feb., pp. 215–220). Brief descriptions are given of each of the common methods of steel-making, with particular reference to current trends in their development.—C. O.

**Random Notes on Some Continental Iron and Steel Making Plants.** A. Jackson. (Lincolnshire Iron and Steel Institute, 1947, Feb. 25). Plant and processes used in Germany for the production of steel from the low-grade ores of the Salzgitter area are described.—J. R.

**Japanese Steel Manufacturing Methods.** (British Intelligence Objectives Sub-Committee, 1947, Report No. B.I.O.S./J.A.P./P.R./755: H. M. Stationery Office). —R. A. R.

**Dephosphorized Bessemer Steel.** G. M. Yocom. (Metal Progress, 1947, vol. 51, Feb., pp. 243–247). A practice for making low-phosphorus Bessemer steel is described. The metal is blown to a temperature of 3150° F. and a thick pasty slag is formed in the converter; this is held back by inserting a block of wood in the converter as it is turned down. A mixture of lime, iron oxides, and flux is added to the stream of blown metal,

and, as the slag which is thus formed mixes with the metal in the ladle, it removes the major portion of the phosphorus from the metal in a few seconds. The properties and applications of this steel are described.—R. A. R.

**New Homestead Openhearths Feature Highly Automatic Control.** R. Urquhart. (Iron Age, 1947, vol. 159, Apr. 3, pp. 46–52). A description is given of the layout and control arrangements at the new steel plant of the Carnegie-Illinois Steel Corporation. This plant consists of eleven 225-ton oil-fired open-hearth furnaces. The devices for automatic reversal control are described in detail.—R. A. R.

**New Method for Building Open-Hearth Flues.** W. F. Conlin. (Steel, 1947, vol. 120, Jan. 20, pp. 94–97). A description is given of the construction of the flues of three 110-ton natural-gas-fired open-hearth furnaces at Donora, Pa. A refractory concrete mixture containing 1 cu. ft. of Lumnite cement to 4 cu. ft. of crushed fireclay brick was poured into position around prefabricated wooden forms. The saving in cost was estimated at 50%, and the performance of the flues has been entirely satisfactory over a period of three years.—C. O.

**Developments in Open Hearth Practice in 1946.** O. P. Luetscher. (Blast Furnace and Steel Plant, 1947, vol. 35, Jan., pp. 68–71). Although no radically new modifications in American open-hearth furnace design or practice were made during 1946, shortages in practically all essential requirements resulted in the advancement of many previously known but not widely appreciated developments.—J. R.

**Operating a 180-Ton Open-Hearth Furnace with Ends and Main Roof of Basic Construction.** A. K. Moore. (Blast Furnace and Steel Plant, 1947, vol. 35, Jan., pp. 92–94). An illustrated account is given of the operation, at the works of the Steel Company of Canada, Ltd., of a 180-ton open-hearth furnace with ends and main roof of basic refractories.—J. R.

**Statistical Analysis of Steelmaking Data.** N. H. Bacon. (Iron and Coal Trades Review, 1947, vol. 154, Jan. 17, pp. 119–126). Statistical analyses by means of frequency-distribution tables and diagrams, Student's test, and factorial design are explained, and the application of the methods to open-hearth furnace data and control is demonstrated. Numerous examples taken from actual steelworks practice are included.—J. R.

**Iron Substitutes in Open-Hearth Charges.** R. R. Fayles. (Iron Age, 1947, vol. 159, Jan. 23, pp. 57–59). A critical survey is made of the carbonaceous materials which are available as substitutes for pig iron for increasing the carbon content of scrap melts in open-hearth furnaces. The two most widely used are anthracite and by-product coke. The amount of the former which can be added is limited by the foaming resulting from hydrogen evolution. The results of adding by-product coke are not consistent, being influenced by the time of charging. A practice has been developed, using these two materials in combination, to take advantage of their desirable properties and minimize their defects.—C. O.

**Some Recent Trends in Process Controls for Steel Making.** H. J. Forsyth. (Blast Furnace and Steel Plant, 1947, vol. 35, Jan., pp. 76–81). Substantial progress in quality control was made by the American steel industry during 1946, and some of the methods used are reviewed.—J. R.

**The Use of Oxygen for Steelmaking in Reverberatory Furnaces.** V. A. Mozharov. (Iron and Steel Institute, 1947, Translation Series No. 306). This is an English translation of a paper which was published in Kislorod (Oxygen), 1946, No. 1, pp. 1–14. The use of oxygen-enriched air in reverberatory furnaces, especially the open-hearth furnace, is discussed, with particular reference to the optimum size of furnace and weight of charge, and the possibilities of increasing the rate of melting, using low-grade fuel, reducing the cost of converting pig iron into steel, and simplifying the furnace design. A closed-circuit furnace not requiring regenerators is considered.—D. R. S.

**Oxygen Accelerated Combustion in Open-Hearth Furnaces.** E. T. W. Baily. (Engineering Journal,1947, vol. 30, Feb., pp. 48–50). *See* Journ. I. and S. I., 1947, vol. 156, May, p. 132.

**Carburetting and Heating Open-Hearth Furnaces with Pulverized Coal.** K. Guthmann. (Stahl und Eisen, 1947, vol. 66–67, Mar. 27, pp. 116–122). German experience in the use of pulverized coal as a carburetting agent for gas-fired open-hearth furnaces and American experience with pulverized-coal-fired open-hearth furnaces are reviewed.—R. A. R.

**Developments in the Control of Arc Furnaces.** E. H. Browning. (Blast Furnace and Steel Plant, 1947, vol. 35, Jan., pp. 72–75). Various designs of electric-arc-furnace regulators are discussed, with special reference to the balanced-beam and the rotating types.—J. R.

**Japanese Methods of High Frequency Induction Heating and Melting.** (British Intelligence Objectives Sub-Committee, 1947, Report No. B.I.O.S./J.A.P./P.R./760 : H.M. Stationery Office).—R. A. R.

**Basic Open-Hearth Slags.** K. L. Fetters and E. W. Mahaney. (Iron Age, 1947, vol. 159, Mar. 6, pp. 62–66 ; Mar 13, pp. 64–68). The following characteristics of open-hearth slags and their effect on the production and quality of the steel are discussed : (*a*) Volume ; (*b*) basicity ; (*c*) oxidizing power ; and (*d*) fluidity. The mineral phases present in slags, their identification, and the control of heats by the examination of slag cakes are also considered with numerous references to the literature.—R. A. R.

**Graphite Molds for Casting Vertical Steel Ingots.** S. W. House and T. Killman. (Iron Age, 1947, vol. 159, Jan. 16, pp. 59–63). The experience of the Texas Steel Company with a vertical graphite mould for pouring steel ingots is recorded. The mould, for an ingot weighing 233 lb., was constructed in two parts fastened together by studs and steel straps. Before it was discarded, 538 ingots were cast in it, compared with an average of 36 in standard iron moulds. Other advantages noted were : Immunity from sticking and better surface condition of ingots, improved ingot grain-structure and reduction in segregation at the centre ; and fewer inclusions in the steel because of the absence of mould wash. There was no carbon pickup from the mould, since less than $\frac{1}{4}$ lb. of graphite was lost during its life. Although the graphite mould cost four times as much as an iron one, fourteen times as many ingots were cast in it, so that the net saving in mould cost was 75%.—C. O.

**Life of Ingot Moulds.** K. Knehans and N. Berndt. (Technische Mitteilungen Krupp : Iron and Coal Trades Review, 1947, vol. 154, Jan. 31, pp. 231–235). The literature on the effect of chemical composition, microstructure, casting procedure, and heat-treatment on the life of ingot moulds is reviewed.—C. O.

**Solidification of Killed Steel Ingots.** J. W. Spretnak. (Industrial Heating, 1947, vol. 14, Feb., pp. 244–248, 298–299). The kinetics of the solidification of killed-steel ingots are discussed.—J. R.

## HEAT-TREATMENT AND HEAT-TREATMENT FURNACES

**Mass Production Heat Treating.** (Steel, 1947, vol. 120, Mar. 24, pp. 88–90). A fully mechanized heat-treatment plant for hardening and tempering small

parts loaded on trays is described.—R. A. R.

**Continuous Hardening Quenching Washing Drawing Forgings.** (Steel, 1947, vol. 120, Mar. 24, pp. 84–86). An illustrated description is given of a continuous heat-treatment plant for dealing with large quantities of small drop forgings.—R. A. R.

**The Calculation of Nickel–Chromium Resistors in Heat-Treating Furnaces.** V. Paschkis. (Industrial Heating, 1946, vol. 13, Dec., pp. 1972–1988). The design of nickel–chromium resistances for electrical furnaces is discussed and the calculation of the dimensions of the resistances is explained.—C. O.

**Precipitation Hardening.** D. S. Kemsley. (Australian Institute of Metals: Australasian Engineer, 1946, Aug. 6, pp. 79–86; Sept. 7, pp. 50–57; Oct. 7, pp. 37–44). The precipitation-hardening of metals is reviewed under the following headings: (1) Early observations and the first theory of precipitation-hardening; (2) the theory of precipitation-hardening; (3) nucleus formation; (4) types of precipitation; (5) property changes accompanying precipitation; (6) other theories of precipitation-hardening; (7) practical applications of precipitation-hardening; (8) aluminium-base alloys; (9) magnesium-base alloys; (10) ferrous alloys; (11) copper-base alloys. —R. A. R.

**Suspended Carburization.** S. L. Widrig, J. E. Reed, and O. E. Cullen. (Materials and Methods, 1947, vol. 25, Feb., pp. 65–68). A description is given of a technique evolved to reduce the time lost by week-end shutdowns in continuous gas-carburizing furnaces. By controlling the composition of the gas and the temperature it has been found possible to "suspend" the carburizing action and hold the charge in the furnace for up to 72 hr. without harm.—C. O.

**The Growing Use and Importance of Prepared Atmospheres.** E. G. deCoriolis. (American Gas Association: Industrial Heating, 1947, vol. 14, Feb., pp. 226–234). Fields of application of controlled atmospheres in the metal industries are discussed, with special reference to carbon restoration, prevention of decarburization, gas quenching, dry cyaniding, and dew-point control.—J. R.

**Dies Harden in Passing.** J. A. Schaefer. (Machinist, 1947, vol. 90, Feb. 15, pp. 1833—1835). By the use of high-frequency induction-heating equipment with sensitive electronic controls it has been possible to utilize a less expensive 0·4–0·5% carbon steel instead of S.A.E. 415 in the production of press-brake forming dies at the Dreis and Krump Manufacturing Company, resulting in a superior product. The selected working surface is hardened to about 48—50 Rockwell C and to a required uniform depth, by guiding the die, mounted on a carriage which travels at a predetermined electronically controlled speed, past an individually designed heating coil stationed at a closely controlled distance from the untreated surface. The carriage speed can be varied from 0 to 15 ft./min., male and female dies being heat-treated at the rate of 5–6 ft. and 3½–5 ft./min. respectively. Details of the high-frequency equipment, the quenching and cooling water sprays, and the safeguards against overheating are given.—R. L. B.

**Induction Heat-Treatment of Tools.** E. F. Watson. (Machinery, 1947, vol. 70, Mar., pp. 287–288). The application of induction heating to the heat-treatment of tools is briefly described. The high-frequency currents may be divided into three ranges, according to whether the generator is a rotating machine, a spark-gap converter or a thermionic-valve oscilator—R. L. B.

**Caustic Soda as a Quenching Medium for Steel.** K. Rose. (Materials and Methods, 1947, vol. 25, Jan., pp. 75–77). The use of caustic soda for quenching both small and large forgings at Park Drop Forge Co., Cleveland, Ohio, and for car components at the Ford Motor Co., is described. The advantages and disadvantabes of utilizing "caustic quenching" are given. The relative values of various quenching media, especially water, are described, together with the effect of concentration of caustic soda on the cooling rate of the solution. —R. L. B.

**Quenching of Tool Steels.** E. F. Watson. (Machinery, 1947, vol. 70, Jan. 30, p. 139). A very brief account is given of the quenching media used in hardening tool steels. A table contains data on the relative cooling powers of oil, water, and brine.—C. O.

**Martempering.** (Machinery, 1947, vol. 70, Mar. 13, pp. 265–266). A brief explanation is given of the operations of martempering.—C.O.

## WELDING AND FLAME-CUTTING

**Electrical and Allied Developments of 1946.** G. Bartlett. (Steel Processing, 1947, vol. 33, Jan., pp. 17–21). Developments by an electrical manufacturing company in the field of heating, welding, and metering equipment are reviewed.—R. A. R.

**A Few Observations on Solid Phase Bonding.** G. Durst. (Metal Progress, 1947, vol. 51, Jan., pp. 97–101). Theoretical aspects of the formation of bonds between metals in the solid state are discussed, with numerous references to the literature. The part which absorbed gases and oxide films play in solid phase bonding or pressure welding is not fully understood.–C. O.

**Methods of Studying the Behaviour of Steel during Welding.** H. Granjon. (Sheet and Strip Metal Users' Technical Association: Sheet Metal Industries, 1947, vol. 24, Feb., pp. 385–391). Experimental techniques, developed in France, are described which enabled the thermal cycles occurring in 10-mm. steel plate during oxy-acetylene or arc welding to be reproduced and correlated with the macro-and microstructures obtained in the different zones in order to obtain weldability data.—R. A. R.

**Chemical Composition of Austenitic Welding Electrodes.** R. K. Lee. (Metal Progress, 1947, vol. 51, Mar., pp. 445–447). A study of 171 heats of 18/8 electrode-wire steel has shown that the chromium content must be at least twice the nickel content, and the carbon and phosphorus must be as low as possible, to avoid root cracks in welded metal. Nitrogen induces crack-sensitivity in 25/12 chromium–nickel steel.—C. O.

**Development of the Agil R.N.D. Electrode for Welding German Armour Plate.** (British Intelligence Objective Sub-Committee, 1947, Final Report No. 1227: H.M. Stationery Office).—R. A. R.

**Economics of Arc Welding.** J. A. Dorratt. (Welding, 1947, vol. 15, Jan., pp. 2–10). The author discusses the individual factors of material preparation, design, electrode size, welding current, operating cycle, and accuracy which affect the ultimate cost of arc-welded structures.—C. O.

**Heliarc Welding.** R. J. Anderson. (Canadian Metals and Metallurgical Industries, 1947, vol. 10, Jan., pp. 14–21). The construction of a water-cooled torch for the Heliarc welding process is described. Typical applications of the process are for welding magnesium and aluminium, both in sheets and as cast, and for fabricating structures of stainless steel.—C. O.

**How to Clean Welds.** T. L. Adas. (Iron Age, 1947, vol. 159, Feb. 20, pp. 44–46). The effects of various kinds of foreign materials upon the quality of welds are described and recommendations are made for methods and tools by which metal can be prepared for welding. —C. O.

**Maintenance of Arc Welding Plant.** E. W. Harding. (Welding, 1947, vol. 15, Jan., pp. 25–28). The common defects in arc-welding equipment are summarized and recommendations for routine maintenance are made. —C. O.

**Recommended Spotwelding Procedures.** F. S. Dever. (Iron Age, 1947, vol. 159, Jan. 30, pp. 46–50). Recommendations are made for the design, fabrication, and welding of spot-welded structures.—C. O.

**Uniform Welding Results Obtained by Equalizing Current and Pressure.** M. Thomson. (Steel, 1947, vol. 120, Mar. 17, pp. 101–102). A device for equalizing the current and the mechanical pressure in multiple-spot-welding machines is described. In the case of a 3-tip electrode, the holder carries three copper bars 1-in. square × 10 in. long; these are held by a bolt at one end, the tip being mounted at the other, and the bars act as springs.—R. A. R.

**Resistance Welding of Spring Steel to Low-Carbon Steel.** A. Willink. (Welding Journal, 1947, vol. 26, Jan., pp. 30–31). A short description is given of a technique developed for welding spring steel to low-carbon steel in the manufacture of "snap" fasteners. The main problem, the prevention of drastic quenching by the water-cooling of the resistance-welding electrodes after welding, was solved by surrounding the weld by other metal at a temperature above the critical point at the time of ejection, or by the removal of the electrode before any quenching could take place.—C. O.

**Resistance Welding of Stainless Steels.** J. J. Riley. (Machinist, 1947, vol. 90, Mar. 29, pp. 2010–2013). The welding characteristics of stainless steels are tabulated according to the dominating microstructural phase. The need for close control over the many variables in spot and projection welding is stressed, and a suitable application for projection welding is mentioned. —R. L. B.

**Resistance Welding in Mass Production—Selection of the Process.** A. J. Hipperson and T. Watson. (Welding, 1947, vol. 15, Jan., pp. 11–24; Feb., pp. 61–69; Mar., pp. 117–124). As an introduction to a comprehensive survey of resistance welding from the viewpoint of the production engines, the suitability of the different welding processes for various materials and types of joint is discussed in Part I, whilst the effect of varying several conditions in spot-welding technique is dealt with in Part II. Spot-welding machines and their maintenance are described in Part III.—R. A. R.

**Submerged Melt Welding of Locomotive Boilers.** (Steel, 1947, vol. 120, Feb. 10, pp. 94–95, 125–130). A short description is given of the procedure followed in fabricating locomotive boilers for the Canadian Pacific Railway. The Unionmelt welding process was used for longitudinal and cicumferential seams when practicable. —C. O.

**Repair Welding of Steel Castings.** O. T. Barnett. (Foundry, 1947, vol. 75, Jan., pp., pp. 74–77, 202–210). The repair of steel castings by the removal of defects and the deposition of sound metal by welding is discussed under three headings: (1) The removal of the defect and preparation for welding; (2) the determination of the correct welding procedure, based on considerations of ductibility in the heat-effected zone as the criterion of weldability; and (3) the choice of the welding electrode.—C. O.

**Announcement of the Final Report of the Board to Investigate the Design and Methods of Construction of Welded Steel Merchant Vessels.** H. F. Johnson. (Welding Journal, 1947, vol. 26, Jan., pp. 36-37). The general conclusions reached during investigations into the causes of failure of welded merchant ships are summarized. The fractures were the result of stress concentrations produced by structural discontinuities or welding methods, rather than residual stresses. Some steels used in the ships were notch-sensitive at operating temperatures, and the quality of workmanship was not always good. The numbers of welded ships now sustaining fractures is small as a result of the measures taken to improve design and construction.—C. O.

**The Copper Brazing of Steel Assemblies.** J. D. Jevons. (New Zealand Engineering, 1946, vol. 1, Oct. 10, p. 595; Nov. 10, p. 722; Dec. 10, p. 799). A brief history and description of the copper-brazing process and its use in industry are given.—C. O.

**Induction Soldering Stainless Steel Kitchen Utensils.** (Steel, 1947, vol. 120, Jan. 13, pp. 87, 112). The use of a 20-kw., 450-kilocycle induction-heating unit for soldering together the shanks and blades of stainless-steel utensils is briefly described.—C. O.

**Roll Bending and Flash Welding Stainless Steel Turbo-supercharger Rings.** P. B. Scharf. (Iron Age, 1947, vol. 159, Jan. 23, pp. 52–56). A description is given of a process for making rings from stainless-steel bar of either standard or special sections by bending in rolls and resistance butt-flash welding.—C. O.

**Pressure-Welding Stainless Steel Rings.** C. J. Burch, A. L. Rustay, A. Crowell, and S. M. Jablonski. (Steel Processing, 1946, vol. 32, Dec., 782–787, 802–804, 812; Steel, 1947, vol. 120, Jan. 13, pp. 88–95; Welding Journal, 1947, vol. 26, Feb., pp. 129–137). An investigation into the practicability of producing stainless-steel rings up to 20 in. in dia. by welding is described. The method finally evolved consisted of pressing together two semi-circular sections in a hydraulic press while two diametrically opposed oxy-acetylene welds were made. A forging test was devised to serve as a standard of comparison for rings made under different welding conditions. Close control of surface preparation, welding pressure, and rate of heating were essential for the production of satisfactory joints.—C. O.

**Furnace Brazing Steel Insecticide Bombs.** A. T. Cole and H. M. Webber. (Steel, 1947, vol. 120, Jan. 27, pp. 70–73, 110–114). The production of steel containers for liquid insecticide is described and illustrated. The cylindrical body of each container is drawn in two parts from 0·45-in. mild-carbon strip. These parts, together with the value components, are brazed with copper in roller-hearth electrical-resistance furnaces at a rate of 10,000 containers per 8-hr. shift.—C.O.

**Flakes in Welds.** M. Lefevre. (Revue de la Soudure: Welding Journal, 1947, vol. 26, Jan., pp. 57-s–64-s). The conditions under which flakes appear in welds and the causes of these flakes are discussed. The results of investigations of the effect on flaking of hydrogen content, cooling rates, quenching temperatures, stresses, and chemical compositions are compared with those of other workers. Two general conclusions are drawn: (1) Flakes which manifest themselves as "fish eyes" in welds do not constitute a serious danger, since they are only temporary and appear only under stresses approaching the breaking load; and (2) in all cases the defect can be suppressed by a low-temperature heat-treatment or by sufficient heating of the specimen during welding.—C. O.

**Weld Defects.** F. S. Dever. (Welding, 1947, vol. 15, Feb., pp. 79–84). Defects likely to be encountered in arc, gas, spot, and atomic-hydrogen welding are described and remedies suggested.—R. A. R.

**The Prevention of Weld Failures—The Control of Distortion.** O. T. Barnett. (Industry and Welding: Australasian Engineer, 1947, Jan. 7, pp. 59–61). Examples are given of ways in which residual welding stresses

may be reduced to a minimum.—C. O.

**Radiography of Spot Welds in Various Sheet Gages and Dissimilar Gage Combinations.** R. C. McMaster, F. C. Lindvall, and L. P. Gaard. (Welding Journal, 1947, vol. 26, Jan., pp. 19–29). The influence of sheet thickness and the combination of sheets of different thicknesses upon the interpretation of spot-weld radiographs are discussed. Extensive tests with Alclad aluminium sheets of various gauges showed that all the features of the radiographic images of spot welds could be interpreted correctly by a logical extension of the methods used for spot welds between two 0·40-in. sheets.—C. O.

**Inspector's Approach to Radiographs of Mild Steel Butt Welds.** E. Fuchs, L. Mullins, and S. H. Smith. (Transactions of the Institute of Welding, 1947, vol. 10, Feb., pp. 19–36). A short training course which was given to a number of engineering inspectors to help them assess the quality of welds by the interpretation of radiographs is described.—R. A. R.

**Japanese Welding Standards.** (British Intelligence Objectives Sub-Committee, 1947, Report No. B.I.O.S./J.A.P./P.R./613 : H.M. Stationery Office). The welding specifications of the Japanese navy are given.—R. A. R.

**New Oxygen–Arc Process for Cutting Ferrous and Non-Ferrous Alloys.** H. R. Clauser. (Materials and Methods, 1947, vol. 25, Jan., pp. 78–81). The cutting of ferrous and non-ferrous metals up to 3 in. thick has been made possible by the oxygen-arc process developed by the Arcos Corporation. The development and mode of operation during cutting and piercing are briefly described. The equipment is described in detail.—R. L. B.

**Oxy-Acetylene Cutting in the Fabrication of Steel Structures and Small Parts.** W. K. Thompson. (New Zealand Engineering, 1947, vol. 2, Feb. 10, pp. 181–182). Example of oxy-acetylene cutting with the "straight line and circle" cutting machine are described. They show that a very high degree of accuracy can be obtained. —R. A. R.

**City Gas and Oxygen Mixture Effective in Flame-Cutting Steel.** (Steel, 1947, vol. 120, Mar. 24, p. 77). The use of town gas (at a mains pressure of 5 oz.) with oxygen for flame-cutting steel up to 12 in. in thickness is reported.—R. A. R.

**Powder Cutting of High Alloys.** D. H. Fleming, jun. (Materials and Methods, 1947, vol. 25, Feb., pp. 73–76). An account is given of a method of cutting high-alloy steels using a stream of oxygen into which an iron-rich powder is introduced.—C. O.

## PROTECTIVE COATINGS

**Modern Electro-Plating Equipment.** (British Engineering Export Journal, 1947, vol. 29, Feb., pp. 982–988). This is an illustrated review of up-to-date electro-plating plant and processes.—R. E.

**Apparatus for Anodically Stripping Electrodeposits from One Side of a Sheet for Analytical Purposes.** J. W. Price. (Journal of the Electrodepositors' Technical Society, 1947, vol. 22, pp. 22–23). A short description is given of an apparatus for the electrolytic removal an electrodeposit from only one side of a sheet.—C. O.

**Bright Chromium Plating and Temperature Control.** M. G. Herback and C. W. Bowden, jun. (Metal Progress, 1947, vol. 51, Feb., pp. 257–259). The process of bright chromium plating is described with special reference to automatic temperature control systems for the pickling and plating tanks.—R. A. R.

**Note on the Effect of Copper on Nickel Deposition.** G. E. Gardam. (Armament Research Department : Journal of the Electrodepositors' Technical Society, 1947, vol. 22, p. 14). Brief mention is made of an experimental determination of the amount of copper which can be present in nickel anodes without them giving rise to "growthy" deposits.—C. O.

**Effect of Small Amounts of Zinc in Watts Type Nickel Depositing Soultions.** G. E. Gardam. (Armament Research Department : Journal of the Electrodepositors' Technical Society, 1947, vol. 22, pp. 8–13). Experimental results of the effect of zinc in Watts-type nickel-depositing solutions are presented.—C. O.

**Some Fundamental Aspects of the Hot-Dip Galvanising Process.** W. L. Hall and L. Kenworthy. (British Non-Ferrous Metals Research Association : Sheet Metal Industries, 1947, vol. 24, Apr., pp. 741–752, 758). Research work carried out up to 1939 on the manner in which the characteristics of the zinc coating may be modified by variations in galvanizing technique is reported. Particular reference is made to : (*a*) Control of the weight and structure of the coating by varying the time of immersion, dipping temperature, and rate of withdrawal ; and (*b*) the effect of additions of aluminium, tin, antimony, and cadmium to the bath.—R. A. R.

**Galvanized Steel Wire.** F. M. Crapo. (Wire and Wire Products, 1947, vol. 22, Jan., pp. 31–42). The history and the present state of the art of galvanizing steel wire are reviewed. An appendix contains 81 references to the literature.—C. O.

**The Tainton Electro-Galvanising Process for Brylanized Wire.** H. Roebuck and A. Brierley. (Journal of the Electrodepositors' Technical Society, 1946, vol. 21, pp. 91–101). A detailed illustrated description is given of a galvanizing process in which zinc is deposited directly on to travelling wire cathodes from an electrolyte of zinc sulphate made from roasted zinc blende ore.—C. O.

**Production Control Formulae for the Tinning of Steel Sheets.** J. H. Mort. (Sheet Metal Industries, 1947, vol. 24, Mar., pp. 521–530). Scales and nomograms are presented which facilitate the rapid calculation of variables such as thickness and weight of coating, speed of travel through the bath, and current density and voltage, in the hot-dip and electrolytic tinning processes.—C. O.

**Some Observations on Mottled Tinplates.** A. Hamelain. (Sheet Metal Industries, 1947, vol. 24, Mar., pp. 543–546, 548). Experiments made to determine the mode of occurrence of the defective, dull areas, known as "mottle" which appear on certain tinplates are described. The mottling originates in a particular pattern of the iron–tin alloy layer ; the characteristics of this pattern vary with the speed of passage of the sheets through the flux–tin interface. It is suggested that the appearance is governed by the way in which the flux is removed from the surface of the base metal as it passes into the tin.—C. O.

**Tinplate Manufacture in Western Germany.** (British Intelligence Objectives Sub-Committee, 1947, Final Report No. 1216 : H.M. Stationery Office). An account is given of the processes used by the German tinplate industry during the war. In general a preference was shown for open-hearth steel. The quality of the tinplate samples examined was inferior to the product of modern British and American continuous strip-mill practice. —C. O.

**Electro-Tinplate. Part II—The Influence of Coating Thickness on the Porosity and Resistance to Corrosion of Electro-Tinplate.** R. Kerr, R. M. Angles, and K. W. Caulfield. (Journal of the Society of Chemical Industry, 1947, vol. 66, Jan., pp. 5–7). The effect was studied of variations in the thickness of the coating, between 2 and 133 oz. per basis box, on the quality of electro-tinplate deposited from stannous sulphate and sodium

stannate baths. Specimens were subjected to the tests described in Part I of this paper (*see* Journ. I. and S. I., 1947, vol. 156, May, p. 138). All these tests indicated a deterioration in the quality of the deposit with decreasing thickness, the deterioration becoming rapid from a certain minimum thickness, about 12 oz. per basis box, onwards.—D. R. S.

**Electro-Tinplate. Part III—The Influence of Pickling Conditions on the Porosity and Corrosion Resistance of Electro-Tinplate.** K. W. Caulfield, R. Kerr, and R. M. Angles. (Journal of the Society of Chemical Industry, 1947, vol. 66, Jan., pp. 7–11). The quality of tin coatings electrodeposited from acid and alkaline baths after various pickling procedures was determined by visual examination and by some of the tests described in Parts I and II. Pickling was carried out in various acid solutions and by anodic etching in sulphuric acid in the absence and presence of inhibitors. It was found that coatings of equally high quality can be deposited from either bath, but the deposit from the alkaline bath is less sensitive to the preceding pickling procedure than that from the acid bath. The best pretreatment for alkaline bath deposits is pickling in inhibited sulphuric acid, and for acid bath deposits the best is anodic etching in sulphuric acid. Pickling in hydrochloric acid leads to coatings of slightly lower quality, but prolonging the pickling time up to 5 min. has no deleterious consequences.—D. R. S.

**A New Time-of-Gassing Test of Thickness of Cadmium Coatings, Particularly for Small Parts.** S. G. Clarke and J. F. Andrew. (Armament Research Department: Journal of the Electrodepositors' Technical Society, 1947, vol. 22, pp. 1–7). The use of a nickel salt to equalize the rate of solution during gassing tests on cadmium coatings is described.—C. O.

**Flame Spraying by the Powder Pistol.** W. D. Jones. (Sheet and Strip Metal Users' Technical Association: Sheet Metal Industries, 1947, vol. 24, Feb., pp. 375–382; Foundry Trade Journal, 1947, vol. 81, Feb. 13, pp. 157–158, 161; Engineering, 1947, vol. 163, Apr. 11, pp. 297–299). Developments in the methods of forming protective coatings by spraying powdered metals, synthetic rubber, and polythene are described.—R. A. R.

**Metal Powders.** H. W. Greenwood. (British Engineering Export Journal, 1947, vol. 29, Apr., pp. 1277–1279). The term "metallurgy of powders" is applied to all those uses of powder, such as spraying, calorizing, sherardizing, etc., to certain solders, and to reduction processes of the thermit type. On the other hand, "powder metallurgy" is used to distinguish those processes in which metal parts are moulded from powders by pressing and sintering. The application of powder metallurgy for the production of porous metal filters for the chemical industry is noted and developments in the use of the Schori metallizing process for the protection of metal surfaces are outlined.—R. E.

**Corrosion-Preventing Coatings of Buna S-Ebonite.** (British Intelligence Objectives Sub-Committee, 1947, Final Report No. 953: H.M. Stationery Office). A description is given of the method of lining vessels with an acid- and corrosion-resisting coating of Buna S-ebonite.—R. A. R.

**Electrostatic Spraying of Steel Wall Panels.** W. S. Reed. (Materials and Metals, 1947, vol. 25, Feb., pp. 77–79). A description is given of an automatic equipment for the coating of steel sheets by passing them through a "mist" of paint in an electrostatic field.—C. O.

**Manufacture of Antifouling Paints in Germany and Related Matters.** (British Intelligence Objectives Sub-Committee, 1947, Final Report No. 727: H.M. Stationery Office). German developments in anti-corrosion and antifouling paints are reported on.—R. A. R.

## PROPERTIES AND TESTS

**Biaxial Stresses in Rigid Vessel Simulated in Notched Tension Coupon.** G. Brewer. (Metal Progress, 1947, vol. 51, Jan., pp. 91–96). A description is given of a notched tensile test-piece cut from a steel plate used in investigating the stresses in the vicinity of the seams in welded pressure vessels. Tests with electrical strain gauges showed that the bi-axial stresses developed in the neck of the test-piece were very similar to those found near welds.—C. O.

**A Statistical Survey of Some Hardened Steel Forgings.** R. F. Mather. (Metal Progress, 1947, vol. 51, Jan., pp. 79–85). Statistics are presented on the tensile strengths, Chary impact strengths, and "$Y$" and "$P$" factors of plain carbon and alloy steel forgings used in the manufacture of the Jeep and its trailer. The "$Y$" factor is the ratio (in per cent.) of yield strength to tensile strength; and $P$ = (tensile strength/1000 + 6 × reduction in area) ÷ 5. It is considered that the writing of specifications for tensile properties may be improved by adjusting the requirements for yield strength and reduction of area to variations in the tensile strength, which fluctuates unavoidably between certain limits because of variations in steelmaking and processing.—C. O.

**Stress and Strain in Plastic Flow.** W. P. Roop. (Welding Journal, 1946, vol. 25, Sept., pp. 799–823). As an aid to those engaged in the design of ship structures, the author presents some useful concepts of plastic action, emphasizing principally the points at which the treatment of plastic action differs from the familiar treatment of elastic action.—R. E.

**Researches on the Critical Zone of Brittleness in Steels.** J. Lioret. (Bulletin of the Société Française de Métallurgie, 1945, Jan.-June, pp. 19–30). In the Charpy test the measured impact strength of steels depends upon the nature of the fracture. Brittle steels break along the grain bounderies, whilst tough steels form a fibrous fracture which is preceded by crystalline deformations. By altering the conditions of the test the two types of fracture can be obtained in the same steel, giving two intersecting curves which delimit the "critical zone," as was first shown by Kuntze in 1930. The author has made a careful study of the impact test by altering successively the thickness of the specimen the sharpness of the notch, and the temperature of the specimen.

The thickness of the specimens was varied between 10 and 40 mm. The crystalline type of fracture did not vary with a heat-treated 0·32% carbon steel, but, with overheating, the fracture became fibrous with the thin specimen and reverted gradually to crystalline with increasing thickness. A low-alloy nickel–chromium steel had a fibrous fracture at all thicknesses. Notches 5 mm. deep, but of varying radius, were ground into 10 mm. thick specimens of three steels, in the air-cooled, furnace-cooled and heat-treated, and annealed conditions. As the radius increased, the difference between the resilience of brittle and non-brittle steels tended to even out.

Tests were made at temperatures down to −80° C. Apart from a decrease in the resilience, the curves show no dispersion, not even when the fracture changed from crystalline to fibrous. The author suggests that the

standard test could be improved by grading steels according to the maximum notch radius giving a fibrous fracture.—R. A. H.

**Correlated Brittle Fracture Studies of Notched Bars and Simple Structures.** C. W. MacGregor, N. Grossman, and P. R. Shepler. (Welding Journal, 1947, vol. 26, Jan., pp. 50-s–56-s). The transition from ductile to brittle fracture in metals has been investigated by correlating the results of tests with notched steel bars and thin circular discs of the same steel, simply supported at the edges and bent by a centrally applied force. It was found that a notched bar could be obtained which had the same ductile-brittle transition temperature at the same deflection velocity as the disc.—C. O.

**A Thermodynamic Theory of the Fracture of Metals.** E. Saibel. (American Institute of Mining and Metallurgical Engineers, Technical Publication No. 2131; Metals Technology, 1947, vol. 14, Feb.). On the asumption of a relationship between fracture and the phenomenon of melting, and on the basis of a simple model of the liquid state, the critical condition for the fracture of metals has been derived. Results obtained, using the equation in cases of purely brittle fracture, are in accord with earlier theoretical calculations and, in cases of fracture preceded by plastic flow, are in general agreement with experimental values. The hypothesis of a "microcrack" structure before fracture is shown to be unnecessary.—C. O.

**Cast Steel—Homogenization Heat Treatments.** J. G. Kura and P. C. Rosenthal. (American Foundryman, 1946, vol. 10, Nov., pp. 22–38; Dec., pp. 35–47). The effects of homogenizing heat-treatments for 2, 6, and 12 hr. at temperatures in the 1650–2050° F. range, and for 12 hr. at 2250° F. on the hardenability and mechanical properties of 2-in. cast plates of five low-alloy chromium–nickel–molybdenum steels were investigated. Generally speaking, the treatments produced no appreciable changes in these properties.—R. A. R.

**Non-Destructive Magnetic Inspection of Steel.** R. L. Cavanagh. (Steel Processing, 1946, vol. 32, Nov., pp. 730–732, 737). A description is given of the operation and applications of an instrument known as the "Ferrograph." It consists of a primary and secondary coil, the former energized by a current of 23 cycles/sec., establishing an alternating magnetic field in the sample to be tested, which forms its core. The harmonic components of the voltage induced in the secondary coil are analysed on the screen of a cathode-ray tube. A correlation exists between the fundamental and third harmonics of the secondary voltage and the magnetic variables of the core which enables variations in the physical properties of the latter to be detected. A typical application of the instrument is in the sorting of two sets of mild steel bolts, varying in hardness by 15 points Rockwell, which were mixed during heat-treatment.—C. O.

**A New Radar Transformer Steel.** G. H. Cole and R. S. Burns. (Materials and Methods, 1946, vol. 24, Dec., pp. 1457–1460). An account is given of the properties of a steel containing 3% of silicon and less than 0·01% of carbon, developed in America for rolling into strip 0·002-in. thick for use in the transformers of radar equipment. The strip was cold-rolled in a Sendzimir mill, the degrees of reduction and heat-treatment being carefully controlled to ensure the optimum combination of high permeability and low hysteresis and core loss.—C. O.

**Experimental Study of the Field of Tension by the Rupture of an Adhering Layer.** J. F. Borges. (Instituto Para a Alta Cultura, Centro de Estudos de Engenharia Civil: Técnica, 1947, No. 4, Reprint). (In Portuguese). The distribution of stresses on the surfaces of steel, glass, wood, bronze, and brass was studied by means of brittle lacquer coatings.—R. A. R.

**Some Unusual Tests of Cast Iron.** J. S. Vanick. (Foundry, 1947, vol. 75, Jan., pp. 66–71; Feb., pp. 78–83). Short notes are made on methods, other than the A.S.T.M. standard methods, which have recently been used in testing cast irons. They include bending tests on I-beams, compression tests on specimens with a 60° notch, tensile tests on small and hollow specimens, determinations of elasticity and deformation with electrical strain gauges, torsion tests on hollow specimens, and special corrosion tests.—C. O.

**Hot-Rolling Iron–Carbon Alloys.** E. Piwowarsky and A. Wittmoser. (Iron Age, 1947, vol. 159, Feb. 6, pp. 52–57; Feb. 13, pp. 63–65). **Hot-Rolling of Iron–Carbon Alloys with Over 1·7 Per Cent. Carbon.** E. Piwowarsky and A. Wittmoser. (Foundry Trade Journal, 1947, vol. 81, Feb. 6, pp. 125–132). Bars 0·63 in. in dia. × 7·8 in. long of a cast iron containing carbon 2·8% and silicon 1·1% were hot-rolled and the effect of changes in the rolling conditions on the properties of the product were studied. The best rolling properties and the maximum temperature range in the plastic state were obtained when the phosphorus content, was below 0·1%. The properties were unaffected by changes in the speed of rolling in the 0·8–32·8 ft./sec. range. The maximum improvement in the mechanical properties was obtained with reductions of 60% to 80%.—R. A. R.

**The Izod Impact Strength of Heat-Treated Alloy Steel.** W. Crafts and J. L. Lamont. (American Institute of Mining and Metallurgical Engineers, Technical Publication No. 2134: Metals Technology, 1947, vol. 14, Feb.). An investigation of the Izod impact strength of commercial-quality alloy steels after a simple oil-quench and tempering treatment is described. It was found that Izod impact strength (as measured in horizontal tests at room temperature) is controlled by hardness, degree of hardening upon quenching, and grain-size. In fine-grained steels the impact strength for any given degree of hardening is inversely proportional to the tempered Rockwell C hardness, and the ratio of impact strength to hardness is lowered by incomplete hardening.—C. O.

**Some Problems of Cylinder Bore Wear.** W. A. Robotham. (Journal of the Institution of Automobile Engineers, 1947, vol. 15, Jan., pp. 115–145). This paper outlines some factors bearing on the life of automobile engine cylinders, questions previously recommended palliatives, and suggests that a solution exists to the problem of extending the mileage between reborings.—R. A. R.

**Metallurgy.** E. S. Kopecki. (Iron Age, 1947, vol. 159, Jan. 2, pp. 96–103). The progress in the technology of metallurgy made during 1946 is reviewed. The main advances were achieved in the fields of high temperature, powder metallurgy, vacuum melting, hardenability, die-casting, and X-ray inspection.—C. O.

**The Creep of Metals.** E. Orowan. (West of Scotland Iron and Steel Institute, Feb., 1947, Preprint). The conventional technical creep test, carried out under a constant tensile load, is discussed analytically. If the test is performed at constant stress, the curve obtained

can be resolved into two components, the transient and the persistent, or "quasi-viscous." Transient creep, which can be observed at all temperaturs, begins with a very high velocity and vanishes with time; quasi-viscous creep has, at constant stress, a constant strain rate which vanishes as the temperature falls below a certain range characteristic of the material. The latter-type of creep is caused by atomic rearrangement in regions of disorder, mainly activated by thermal movement, and it is substantially independent of stress and time. The quasi-viscous component is usually predominant at temperatures high relative to the melting point, and at low rates of deformation.

The deceleration of the transient creep cannot be explained on the classical "recovery" theory of creep, or by modifying the Becker formula into the "mechanical equation of state." It is suggested that during the sudden extension which follows the sudden application of stress, plastic deformation progresses without help from thermal stress fluctuation. At the end of this sudden extension, the applied stress and the "no-creep" yield stress are equal. In the course of the subsequent transient creep, further strain-hardening takes place and the yield stress rises above the applied stress. Plastic deformation nevertheless continues because the applied stress is raised from time to time by thermal stress fluctuation to the value of the "no-creep" yield stress. A theory has been developed on this basis which gives very good agreement with experimental results.—C. O.

**The Development of a High Creep Strength Austenitic Steel for Gas Turbines.** D. A. Oliver and G. T. Harris. West of Scotland Iron and Steel Institute, Mar., 1947, Preprint). Details are given of the processes and tests which were carried out in the development of the steel to specification D.T.D. 49B. This a 13/13/10 nickel–chromium–cobalt steel with small additions of tungsten, molybdenum, and niobium. The "warm-working" process by which the 0·1% proof stress at room temperature could be raised to 25–30 tons/sq. in. without sacrificing the high-temperature creep strength, and an X-ray investigation of the phase constitution of steel after various treatments are described.—R. A. R.

**Carbon Absorption of 18–8 at High Temperatures.** W. G. Hubbell. (Steel, 1946, vol. 119, Dec. 30, pp. 86–90). An investigation into the cause of failure of 18/8 stainless-steel aircraft exhaust manifolds, which are subjected to the action of gases at temperatures up to 1700° F., is reported. Chemical and metallographic analysis showed that carbon was picked up from the gases, the amount increasing with the temperature to which the steel was exposed, and that networks of chromium carbide were formed along grain boundaries, but no intergranular corrosion was found. The cause of failure was scaling of the metal because of excessive temperatures resulting from inadequate cooling.—C. O.

**Abnormal Creep in Carbon Steels.** J. Glen. (Journal of the Iron and Steel Institute, 1947, vol. 155, Apr., pp. 501–512). Short-time creep tests at a stress of 8 tons/sq. in. and a temperature of 450° C., have been carried out on a series of low-carbon steels containing 0·4–1·5% of manganese, 0·01–0·15% of silicon, and 0–0·11% of molybdenum, and with varying amounts of aluminium up to 3 lb./ton. It is shown that manganese, silicon, and molybdenum, within the limits examined, reduce the creep rate and that the abnormal creep resulting from aluminium additions is reduced considerably by these elements. In production casts of basic open-hearth steel it is shown that, with proper control, aluminium may be used as a deoxidizer, provided that the steel remains coarse-grained as measured by the McQuaid-Ehn test.

**"Time-Resistance" of Steels under Static Load.** A. Thum and K. Richard. (Mitteilungen der Vereinigung der Grosskesselbesitzer, 1941, Dec. 31, No. 85, pp. 171–197). The concept "time-resistance" (*Zeitfestigkeit*) has been defined as the capacity of a material to withstand a limited number of stress reversals above the fatigue strength until fracture supervenes (*see* Journ. I. and S.I., 1938, No. II, p. 35A). The determination of this property of the steels used in the construction of boilers, tubes and bolts for service at high temperatures and pressures by short-time and long-time tests is dealt with at length. The literature is critically surveyed and new test data, relating in particular to the properties at 500° C., are presented. The results obtained by the German standard short-time creep test A 117/118 (which takes 45 hr.) are considered to be valid only for a few steels, and methods of obtaining more reliable data, such as equipment for making long-time creep tests on many specimens simultaneously, are required as this would assist greatly in the development of new heat-resisting steels. These new steels will be found by seeking the most stable combination of iron, carbon, and alloying elements. A bibliography of 60 references is appended.—R. A. R.

**The Selection of Alloys for Use at Elevated Temperatures.** B. H. Garnsey. (Australian Institute of Metals: Australasian Engineer, 1946, Nov. 7, pp. 68–71). A short history is given of the development of heat-resisting alloys. Their essential properties and the applications of special types of alloys are discussed very briefly.—C. O.

**The Specification of Alloys for Heat-Resisting Castings.** N. A. Matthews. (Industrial Heating, 1946, vol. 13, Nov., pp. 1789–1798). The weaknesses of the usual methods by which the specifications for a given steel casting is drawn up are discussed. It is considered that much more use can be made of the information available from research and experience with heat-resisting alloys.—C. O.

**Heat-Resistant Alloys.** (Materials and Methods, 1946, vol. 24, Nov., pp. 1164–1165). The uses of a heat-resistant alloy containing 16% of chromium, 25% of nickel, and 6% of molybdenum, developed during the war by M. Fleischmann and his colleagues, are discussed.—C. O.

**Requirements of Steels for High Temperature Service.** C. L. Clark. (Metal Progress, 1946, vol. 50, Nov. pp. 897–902). Theoretical aspects of the effect of alloying elements on the high-temperature characteristics of steels containing 5–12% of chromium are discussed. In general, those elements which form solid solutions in iron are most effective in improving the surface stability against oxidation and corrosion, whilst the carbide-forming elements are the most effective in increasing the strength. Chromium, silicon, and aluminium are the important members of the first group, because of their greater affinity for oxygen. Chromium, tungsten, molybdenum, and vanadium are the main carbide-forming elements.—C. O.

**Stress Rupture of Heat-Resisting Alloys as a Rate Process.** E. S. Machlin and A. S. Nowick. (National Advisory Committee for Aeronautics: American Institute of Mining and Metallurgical Engineers, Technical Publication No. 2137; Metals Technology, 1927, vol. 14, Feb.). The theory of rate processes is discussed and its equations are applied to the prediction of the time necessary for the fracture of alloys under constant stress and temperature conditions. Although the successful use of the equations for three alloys is not regarded as conclusive proof that stress-rupture is a rate process, it is suggested that these equations may be used to interpolate and extrapolate data for different temperatures to reduce the number of tests necessary.—C. O.

**Japanese Metallurgy. High Temperature Alloys for Gas Turbines, Rocket Nozzles and Lines.** (British Intelligence Objectives Sub-Committee, 1947, Report No. B.I.O.S./J.A.P./P.R./583 : H.M. Stationery Office). This report enumerates the high-temperature alloys developed in Japan for gas turbines, rockets, etc.—R. A. R.

**The Weldability of Ship Steels.** E. F. Nippes and W. F. Savage. (Welding Journal, 1946, vol. 25, Nov., pp. 776-s–787-s). The results of a study of the relationships between impact strength and testing temperature for a variety of arc welds and their associated heat-affected zones are presented. It was found that the impact strength of the weld metal was not affected by the power of the arc, the speed of travel of the arc, the cooling rate, or the temperature of the preheating. Above room temperature the weld metal was markedly inferior to the original steel, but showed somewhat better impact properties below room temperature. The region of carbide coalescence or spheroidization had the poorest impact properties of the heated-affected zone, but at 200° F. its impact strength was nearly double that of the weld metal.—C. O.

**The Control of Weld Hot Cracking in Nickel–Chromium-Iron Alloys.** T. E. Kihlgren and C. E. Lacy. (Welding Journal, 1946, vol. 25, Nov., pp. 769-s–775-s). An account is given of a study of the hot-cracking of welds in nickel–chromium–iron alloys containing 35–80% of nickel and 15–20% of chromium. It was found that the cracking was due to silicon, and that it could be eliminated by the addition of columbium to the fused metal if the ratio of columbium to silicon were made to exceed a certain value, dependent upon the composition of the parent metal.—C. O.

**Weldable High Strength Steel Castings.** W. J. Crook. (Metal Progress, 1946, vol. 50, Nov., pp. 906–914). Descriptions are given of tests on the welding of high-strength steel castings, in which the following factors were investigated: (1) Effect of previous heat-treatment on mechanical properties; (2) effect of the chemical composition of steel on its weldability; and (3) the effect of welding on the structure of cast steels. A heat-treatment consisting of normalizing at 1700° F., oil-quenching from 1570° F., and tempering at 1000° F. was found to develop the highest tensile strength in the parent metal before welding, without drastically reducing the elongation. Steels of composition 0·25–0·28% of carbon, 0·60–0·70% of manganese, 0·35–0·40% of silicon, 1·40–1·60% of nickel, and 0·30–0·35% of molybdenum gave consistent yield strengths of 65,000-70,000 lb./sq. in. when normalized and tempered, had weld, bead hardnesses of less than 450 Brinell, and were free from any tendency toward weld cracking even in the absence of preheating.—C. O.

**The Development of High-Strength Welding Quality Alloy Steels and Their Postwar Applications.** J. Miller. (Welding Journal, 1946, vol. 25, Nov., pp. 1077–1079). The specifications of a steel developed during the war for use in the welded carriage of a 155-mm. gun are given. The steel, containing 0·16% of carbon, 0·60–0·90% of manganese, a maximum of 0·04% of sulphur and phosphorus, 1·30–1·60% of nickel, 0·90–1·10% of copper, and 0·20–0·30% of molybdenum, is semi-killed, or silicon-killed, and treated with aluminium to control the grain-size. After a 4-hr. stress-relieving treatment at 1100° F., the yield strength is 70,000 lb./sq. in., the weld-bead hardness under standard conditions is less than 300 Brinell, and the fracture in a nick-bend test is tough and grey. This steel has been used in the construction of underframes of railway carriages, but otherwise its commercial applications appear to be limited.—C. O.

**Recent Trends in Concepts of Design for Welded Steel Structures.** L. Grover. (Welding Journal, 1946, vol. 25, Nov., pp. 1091–1108). The results obtained in recent studies of the behaviour of steel materials in actual structures are discussed. Particular reference is made to tests on welded carbon-steel girders and to fatigue tests on welded structures. "Notch effect" or stress concentration can be of great importance even in statically loaded structures, as may be shown by a comparison of the performance of Liberty and Victory ships, the latter being designed so that notch-effects due to welding were eliminated. Conventional acceptance tests for engineering materials and concepts of their behaviour in service are often quite inadequate for providing a basis for safe and economical design. Notched-bar impact tests should be made at or near to the temperature at which the steel will be used. The belief of most designers that a member is upon the verge of failure whenever the stress in any of its fibres reaches the yield point is erroneous. In designing welded structures that are to be subjected to fatigue loading, the guiding principle should be to avoid any notch-like details or abrupt changes in section in order to provide the most uniform practical distribution of stress, in both the base and the weld metal.—C. O.

**Researches on the Mechanism of Pickling Embrittlement. Part II—Behaviour of Hydrogen Introduced into Annealed Mild Steel by Electrolysis or Acid Attack.** P. Bastien. (Revue de Métallurgie, 1945, vol. 42, July, pp. 205–217). In earlier work the author has studied the diffusion of nascent hydrogen into mild steel (*see* Journ. I. and S. I., 1945, No. II, p. 170A). This had shown the existence of a limiting embrittlement below which the hydrogen was driven off by immersion of the steel in water. A comparison is now made between the effect of electrolytic and acid pickling of six different steels with particular reference to the limiting embrittlement.

The experiments were made on four open-hearth steels, Armco iron and a basic-Bessemer steel, using wires 2 cm. in dia. which were normalized and polished. Eighteen wires of each steel were made, six for blank bending tests, six for pickling in 10% HCl for 48 hr., and six for simultaneous pickling in 10% HCl with a cathodic current density of 5·25 milliamp./sq. cm. also for 48 hr. After pickling, the wires were placed in mercury-filled tubes and the hydrogen evolution measured over a period of 1000 hr. In all cases excepting the Armco iron, the hydrogen absorption and evolution were higher with electrolytic pickling than with acid attack, and it varied with the sulphur content of the steel. The Armco iron retained the hydrogen with electrolytic treatment, and took up only very little during acid attack. Some of the electrolytic experiments were repeated with pure $H_2SO_4$ to show that there had been no secondary effects due to the HCl, whilst the addition of 0·01% sodium sulphite to the HCl bath greatly increased the hydrogen absorption. The critical figure was 55 c.c. of hydrogen evolved per 100 g. of steel, beyond which the degree of embrittlement was proportional to the amount of hydrogen evolved. The last point was confirmed (1) by keeping such steel in mercury at 100° C. when the amount of additional hydrogen evolved increased with the embrittlement which had been found and then disappeared, and (2) by heating Armco iron at not higher than 250° C. Armco iron is inherently impervious to hydrogen, and it contains practically no sulphur. Embrittlement, therefore, is not caused by alterations in the microstructure of the metals which could be rectified by heat-treatment, but is a manifestation of the hydrogen remaining in the structure.—R. A. H.

**Some Aspects in the Development of Alloy Steels.** L. Rotherham. (Metallurgia, 1946, vol. 35, Dec., pp. 75–77). A general survey is given of the developments in alloy steels made during and since the war. The subjects specially mentioned are the En classification, heat-treatment, welding, machinability, high-temperature alloys, and casting.—C. O.

**Alloy Steels.** R. A. Archer. (Society of Automotive Engineers: Iron and Steel, 1946, vol. 19, Dec., pp. 787–792). This article on the properties of the NE steels is complementary to an earlier paper on the En steels (*see* Journ. I. and S.I., 1946, No. II, p. 60A). The factors involved in brittle failure are dealt with, and it is concluded that new levels of performance seem attainable as a result of greater knowledge of the conditions necessary for maximum combinations of strength and toughness.—J. R.

**Alloy Steels Intermediate in Chromium.** C. L. Clark. (Metal Progress, 1946, vol. 50, Dec., pp. 1199–1203). The heat-resisting properties of groups of steels containing 4–6% and 6–10% of chromium are discussed with reference to their metallography and the effects of the presence of other alloying elements.—R. A. R.

**Cast Irons—Thermal Stability of Some Chromium–Nickel–Copper Alloys.** W. F. Chubb. (Iron and Steel, 1947, vol. 20, Jan., pp. 19–22; Feb., pp. 59–61). Tests on low-alloy chromium–nickel cast irons with additions of copper are described, the object being to develop an alloy for short-cycle heat-treatment for making chilled rolls.—R. A. R.

**High Tensile Cast Irons.** D. H. Hartley. (British Cast Iron Research Association: Engineer, 1946, vol. 182, Dec. 20, pp. 573–574). A brief account is given of some of the properties of cast iron produced from normal hematite pig iron by a special, still secret, process developed in the laboratories of the British Cast Iron Research Association. A melt of pig iron containing 3·9% of carbon and 2·6% of silicon, when treated by the new method and cast in standard 0·875-in. dia. test-bars, gave a tensile strength of 26·5 tons/sq. in., an Izod impact strength of 47 ft. lbs., and a hardness of 215 Brinell, and was cast and machined with ease. A considerable amount of research is needed before such irons can be produced commercially.—C. O.

**Gray Iron Castings—Section Sensitivity.** H. C. Winte. (American Foundryman, 1946, vol. 10, Oct., pp. 68–75). The effect of the thickness of sections upon the tensile strength and hardness of cast irons is discussed. It is concluded that test-bars can only be used to predict physical properties when the cooling rate of the test bar is comparable to that of the casting. The comparison of cooling rates can be made by considering the ratio of volume to surface area. Internal cores affect cooling rates to an unpredictable extent.—C. O.

**Molybdenum in Cast Iron.** A. E. McRae Smith. (Alloy Metals Review: Foundry Trade Journal, 1947, vol. 81, Jan. 2, pp. 3–6). The beneficial effects of molybdenum on the mechanical properties of grey cast iron are summarized, and data are given on the chemical compositions and properties of the various types of cast iron in which molybdenum is present.—C. O.

**Development in Aircraft Engine Metallurgy, 1920–46.** W. E. Jominy. (Metal Progress, 1946, vol. 50, Oct., pp. 687–690). The author gives an account of some of the metallurgical advances which have influenced aircraft engine design since 1920, mentioning in particular the use of magnesium, silver, stainless steel, chromium plate, sintered copper-tin bushes, forged aluminium, nitralloy steel, grain-size control, hardenability testing, and magnaflux testing.—C. O.

**The Effect of the Permanent Companion Elements and of Alloying Elements on the Properties of Steel.** H. Schropp. (Die Technik, 1947, vol. 2, Jan., pp. 14–18). A comprehensive table is presented which indicates at a glance the effect of 21 different elements on the properties and microstructure of steel. The properties given include the thermal expansion and conductivity, the electrical conductivity, magnetic properties, corrosion and scaling resistance, and response to heat-treatment.—R. A. R.

**Boron in Certain Alloy Steels.** M. C. Udy and P. C. Rosenthal. (American Institute of Mining and Metallurgical Engineers, Technical Publication No. 2085; Metals Technology, 1946, vol. 13, Oct.). The results of a study of the effects of very small amounts of boron on the hardenability and notched-bar impact strength of a nickel–chromium–molybdenum and a manganese–molybdenum steel and of the changes produced by replacing varying percentages of the molybdenum with boron are presented. It is concluded that a boron addition of 0·0015–0·003% can be used to replace half of the molybdenum in aluminium-killed steels of the following average compositions: (1) 0·30% of carbon, 0·85% of manganese, 0·50% of nickel, 0·50% of chromium, and 0·40% of molybdenum; (2) 0·30% of carbon, 1·60% of manganese, and 0·40% of molybdenum. Full deoxidation is necessary to avoid inconsistent hardenability. Boron additions have no apparent adverse effect on notched-bar toughness at temperatures down to − 80° F., nor is any direct effect on susceptibility to temper-brittleness evident.—C. O.

**Properties of Various Alloys at Sub-Zero Temperatures.** (Iron Age, 1946, vol. 158, Nov. 14, p. 75). A summary is given of the results of determinations of the mechanical properties of ferrous and non-ferrous alloys at − 320° F. The ultimate tensile and yield strengths of all the alloys were greater than at room temperature. The ductility of stainless and mild steel was lower than at room temperature. The reduction in temperature lowered the efficiency of seam and arc-welded joints in all the alloys.—C. O.

**New 9% Nickel Steel Tubing—Properties and Processing.** H. S. Newell, J. A. Manfre, and M. A. Cordovi. (Materials and Methods, 1947, vol. 25, Jan., pp. 62–67 and 159–163). This article describes the mechanical properties, the working and welding characteristics and the behaviour on heat-treatment of 9% nickel steel. The chief applications suggested are for tubing where resistance to alkaline liquors, certain organic acids and carbonic acid is required, and for use at sub-atmospheric temperature.—R. L. B.

**Selecting Steels for Casting Dies.** H. Chase. (Steel, 1947, vol. 120, Jan. 13, pp. 98–100, 109). The essential properties of steels used for making dies for the casting of non-ferrous metals are enumerated. Data on the chemical composition and heat-treatment of steels for die-casting zinc, tin, lead, aluminium, magnesium, and copper-base alloys are presented.—C. O.

**Popular Types of Steels.** G. D. Boyer. (Product Engineering, 1947, vol. 18, Jan., pp. 81–85). Recent trends in the specifications for steel for industrial purposes in America are discussed. The shortage of steel is leading to a concentration on the production of a relatively small number of sheets; the machining properties of some of these, in particular the plain carbon ones, are described. It is considered that there is a tendency to replace carbon steels by alloy steels whenever possible, because the latter are now more plentiful and their heat-treatment is less complex.—C. O.

**Substitute Steels.** A. Sourdillon. (Revue de Métallurgie, 1945, vol. 42, Sept., pp. 295–304). The French steel industry from 1940 to 1945 was restricted by the Germans to the development and production of low-alloy steels using mainly silicon and manganese. Whilst such steels were not genuine substitutes for nickel, chromium–molybdenum, vanadium and tungsten steels, the development of accurate heat-treatments improved their qualities to such a degree that they are now finding legitimate application in the French automobile industry, etc. This lecture summarized the status and compositions of constructural, special, and tool steels in 1940 and explains the different stages through which the industry passed. The action of the different alloys and their combinations is illustrated graphically.

New and more sensitive methods of testing steels were devised during the war by Chevenard and Caquot which made it possible to predict the necessary heat-treatment conditions. In conclusion the author quotes the work on surfaces by Portevin and on photo-elasticity by Mesnager as possible aids in the improved design of parts made by the new steels.—R. A. H.

**Rigidized Metal—A Modern Material.** D. E. Olshevsky. (Materials and Methods, 1947, vol. 25, Feb., pp. 93–98). An account is given of the properties and uses of "rigidized" metal, which is sheet or strip with a two-dimensional pattern of impressions designed to increase its strength and rigidity in all directions.—C. O.

**Turbine Disco—Use of Pearlitic Steel in Jet Engines.** (Iron and Steel, 1947, vol. 20, Feb., pp. 63–64).—R. A. R.

**Free Machining Die Steel.** (Steel, 1947, vol. 120, Feb. 10, p. 104). A summary is given of the composition and properties of air-hardening steel which is easily machinable in the hardened state and therefore suitable for plastic moulds and die-casting dies for white metals.—C.O.

**Low-Alloy, High Tensile Steels, Their Properties, Workability and Weldability.** G. M. Huck. (Welding Journal, 1947, vol. 26, Jan., pp. 32–35). An outline is given of the characteristics of the low-alloy, high-tensile group of steels, with particular reference to the type known as "Mayari R."—C. O.

**Some Metallurgical Aspects of Cemented Carbides.** J. C. Redmond. (Iron Age, 1947, vol 159, Jan. 30, pp. 42–45, 150). The existing information on the effect of the "cement" metal, grain-size, and porosity on the physical properties of cemented carbides is summarized. —C. O.

**New Steel Features Improved Hot Hardness.** (Iron Age, 1946, vol. 158, Dec. 12, p. 63). Details are given of the properties of a high-speed tool steel known as "Vasco Supreme," containing 1·5% of carbon and 5% of vanadium. They include a very high degree of wear resistance and a hardness of more than 450 Brinell at a temperature of 1200° F.—C. O.

**Sampling Techniques Applied to Quality Control.** E. Goddess. (Iron Age, 1946, vol. 158, Dec. 12, pp. 70–75, 136A). The theoretical basis of sampling articles from a production line for inspection is discussed. Suggestions are made for determining the optimum sampling technique for routine inspection when time, space, cost, and the loss of articles in destructive testing are important factors.—C. O.

**Investigation into the Inspection Organisation of the German Armament Industry.** (British Intelligence Objectives Sub-Committee, 1947, Final Report No. 1132 : H.M. Stationery Office).—R. A. R.

## CORROSION

**Corrosion Prevention and Protection.** F. R. Morral. (Wire and Wire Products, 1947, vol. 22, Feb., pp. 133–138, 175). The literature on the corrosion of metal is summarized. The bibliography contains 109 references. —C. O.

**Corrosion—The Great Destroyer.** D. J. Fergus. (Corrosion, 1947, vol. 3, Feb., pp. 55–66). The problem of the corrosion of galvanized steel hot water storage tanks is reviewed in some detail. The article includes a number of photographs of the surfaces of tanks fitted with an "Elno" protector, and the use of magnesium and magnesium alloys as anodic protectors is described. —N. S.

**Economics Aspects of Corrosion Problems.** F. A. Rohrman. (Corrosion, 1947, vol. 3, Feb., pp. 67–72). This article is made up from extracts of a speech presented during the General Assembly of the National Association of Corrosion Engineers, held in Kansas in 1946. The introduction is followed by a list of nine factors affecting corrosion costs and these are briefly reviewed.—N. S.

**The Protection of Steam Boilers during Long Periods out of Commission.** A. Langsberg. (Teknisk Tidskrift, 1947, vol. 77. Apr. 19, pp. 371–375). (In Swedish). In order to determine the value of various wet methods of preventing the corrosion of the inside of boilers when not in use, loss-in-weight tests were made by immersing clean pieces of low-carbon steel boiler tube in jars of softened water, distilled water, condensate, and alkali-treated water. The corrosion was less in alkaline condensate than in soft alkali-treated water. There was no corrosion at all in alkali-treated distilled water, which was confirmed by inspecting boilers which had been standing for one year filled with pure condensate to which 400 mg. of NaOH and 75 mg. of $Na_3PO_4$ per litre had been added.—R. A. R.

**Corrosive Action of Boiler Feedwater.** (Engineering and Boiler House Review, 1947, vol. 62, Mar., pp. 89–90). The chemistry of the corrosion of metals when in contact with water is outlined. The reactions of the chief corrosion components contained in any water supply, *viz.*, carbon dioxide, oxygen, and dissolved salts, are discussed, together with methods of overcoming corrosion in feedwater systems.—G. C. J.

**Corrosion of German Naval Boilers with Particular Reference to De-Aeration of Feed Water.** (British Intelligence Objectives Sub-Committee, 1947, Final Report No. 1173 : H.M. Stationery Office).—R. A. R.

**Results Obtained from Five Years of Cathodic Protection on 24-Inch Gas Line Rapidly Deteriorating from Bacterial Corrosion.** W. E. Huddleston. (Corrosion, 1947, vol. 3, Jan., pp. 1–7). An investigation revealed that the excessive corrosion of a 24-in. pipeline passing through poorly drained grassy swamps was probably due mainly to the presence of anaerobic sulphate-reducing bacteria. Excellent results were obtained by applying cathodic protection as was shown by tests lasting five years.—R. A. R.

**Corrosion on Gasworks.** A. J. Brandram. (Manchester and District Junior Gas Association : Gas World, 1947, vol. 126, Mar. 29, pp. 269–373). The corrosion-resistant properties of the steels used for the construction of gas-holders are compared. The protection of such sheets by painting and metal spraying is discussed.—C. O.

BRITISH IRON AND STEEL FEDERATION. BRITISH IRON AND STEEL RESEARCH ASSOCIATION. "*Report on Blast Furnace Practice and Plant.*" 8vo., pp. 66. Illustrated. London, 1946. (Price 10*s.* 6*d.*).

This is a joint report, summarizing the findings of a number of investigators who have recently visited Germany under the auspices of the Combined and British Intelligence Objectives Sub-Committees. It gives an overall picture of German blast-furnace practice during and immediately prior to the war; the most interesting feature is the development of methods of ore preparation for the purpose of making increased use of native ores. It is noteworthy that new German furnaces have all been of the British-American type with inclined hoists and skip charging. Other points of special interest are experiments on blast enrichment, and acid smelting with desulphurization by soda ash. The appendices contain analyses of representative ores (native and imported), furnace profiles, notes on experiments on enlarging the oxidation zone in the hearth, and a series of diagrams of blast-furnaces and auxiliary plant.—M. A. V.

DAVIES, H. J. "*Precision Workshop Methods.*" Second Edition. 8vo. pp. x + 324. Illustrated. London, 1946: Edward Arnold and Co. (Price 20*s.*).

It is a frequently heard platitude that the age of craftmanship has passed. To anyone in touch with modern engineering science, this statement is demonstrably false, but it is not always realized that the craftsman's skill has moved one stage further away from the man in the street. Formerly, the craftsman's product was an article of commerce, whereas now the product of his skill is used by some division of industry, usually in the mass production of highly specialized goods made by relatively unskilled labour. Mr. Davies, in his book, has made a comprehensive contribution to the literature on an aspect of engineering which, although specialized, has a bearing on every branch of the science.

Little more than a general summary of the contents of the seventeen chapters is possible here. The modern necessity for precision methods is outlined and followed by a description of the systems of marking out work and setting up for machining, including the use of jigs and fixtures. The graduation of scales, and machine indexing are next described, then follows a discussion of screws and screw-cutting. The problems associated with the precise production of non-circular and other special outlines are covered in the next chapter, which includes instructions on the use of templates and the making of profile tools, and this leads in turn to consideration of gears and gear-tooth elements. Two further chapters deal with lapping and grinding for precision finish, and include a description of modern methods of surface classification and roughness measurement. Precision measurement and gauging, including the use of limit methods, are the subjects of the next chapter, and finally the author gives methods for the examination and survey of machine tools and attachments.

Mr. Davies writes clearly and concisely and has made good use of line drawings to assist the reader in following the practical geometry of the problems discussed. References to additional literature on the subject matter of each chapter are collected and given at the end of the book. These should prove valuable to those who wish to carry their studies farther than can be accommodated within the scope of a general work such as this. The volume is well printed and bound, and should be an attractive acquisition to all students of production engineering.
S. L. ROBERTON

DURRER, R. "*Grundlagen der Eisengewinnung.*" 8vo, pp. v + 210. Illustrated. Berne, 1947: Verlag Francke, A.G.

This introduction to the extraction metallurgy of iron was written as a concise guide to the subject for the benefit of students of allied branches of technology, and the author has succeeded in presenting a self-contained mass of summarized information, unencumbered by references or cross-references, in a readable form.

The first quarter of the book is devoted to an explanation of the basic chemical and physical principles. This is followed by a very brief historical note, and an outline of economic considerations, in particular, ore and mineral deposits. The remainder of the book describes first the various processes for the manufacture of iron—not only the blast-furnace, but also the more important direct-reduction process, and the electric furnace process—and secondly, the processes for refining iron into wrought iron or steel.

Dr. Durrer has produced a most informative little book, which, despite the very wide field covered, is easy to read; there appears to be no comparable work in the English language at present.—M. A. V.

HIRST, H. "*X-Rays in Research and Industry.*" Second Edition, 8vo, pp. vii + 124. Illustrated. London, 1946: Chapman and Hall, Ltd. (Price 13*s.* 6*d.*).

This book was first published in Australia and is based on a series of lectures given at Melbourne University. X-ray technique is dealt with in a concise and practical way, and special attention is paid to problems in industry and research, particularly metallurgy. In this edition the opportunity has been taken to correct a number of errors which appeared in the text of the first edition. (*See* Journ. I. and S. I., 1943, No. I, p. 146A).—R. E.

LAURSON, P. G. and W. J. COX. "*Mechanics of Materials.*" Second Edition, 8vo, pp. x + 422. Illustrated. New York, 1947: John Wiley and Sons, Inc.; London: Chapman and Hall, Ltd. (Price $4).

The authors have written the book primarily for students, and have taken a considerable amount of trouble to emphasize the definitions and principles involved in a study of the mechanics of materials. It is unfortunate that, for British students, this very emphasis makes the book unsuitable for their use.

A British student having any knowledge of the subject, on reading the book could not help but be confused by the use of terms in common use in America instead of those normally understood in this country, particularly when some of them have been used in a different sense in different parts of the book. For example, in the first chapter, the difference between "total stress" and "intensity of stress" is explained at some length, and then in a later chapter dealing with combined stresses one finds a tensile stress compared with the tension in the extreme fibres. In such instances, the meaning is no doubt quite clear to readers conversant with the subject, but the book is not, after all, written for such readers.

The sections of the book dealing with the properties of materials and methods of testing are brief, whereas subjects which might well have been left to be dealt with in a book on structures have been included in this volume. For example, some pages have been devoted to such items as the design of reinforced concrete members, eccentrically loaded, riveted and welded joints, the design of columns, etc., but not at sufficient

length to enable the student to obtain a proper grasp of the principles governing these. It would have been better to omit these chapters altogether.

There are nearly 900 questions in the book, mainly of the type which tend to give the student practice in the use of formulæ and the slide rule, and it might have been preferable to have more questions testing his aptitude in the application of principles to particular problems.

S. R. SPARKES

RAYNOR, G. V. "*An Introduction to the Electron Theory of Metals.*" (Institute of Metals Monographs and Report Series No. 4). 8vo. pp. x + 98. Illustrated. London, 1947 : The Institute of Metals (Price 7*s.* 6*d.*).

There is a tendency to report present-day progress in the theory of metals in terms unfamiliar to many metallurgists. This monograph is written with this class of reader in mind, and is intended to give a general picture of the development of the theory, to outline some of the ideas which lie behind it, and to indicate its application to physical metallurgy and the properties of metals. The subject is dealt with in the following chapters : (I) Preface ; (II) The New Approach to Metallurgy ; (III) Some Basic Principles of Atomic Theory ; (IV) The Bohr Theory of the Atom; (V) The Probability Conceptions ; (VI) Application to Metals ; (VII) The Effect of Crystal Structure ; (VIII) Application to Alloy Structures ; (IX) Approximations Involved in the Results of the Electron Theories ; (X) Insulators and Conductors ; (XI) Magnetic Properties of Metals and Alloys ; (XII) The Cohesion of Metals ; (XIII Conclusion ; Bibliography. —R. E.

SEELY, F. B. "*Resistance of Materials.*" Third Edition. 8vo., pp. xiv + 486. Illustrated. New York, 1947 : John Wiley and Sons, Inc. ; London : Chapman and Hall, Ltd. Price $4).

The third edition of "Resistance of Materials," by Professor F. B. Seely of Illinois University, is an expanded revision of a well known text book for the American student.

To the British student the title is misleading, since the contents would be more appropriately described as Applied Mechanics. Of 486 pages, only 12 are devoted to informing the reader of the properties of various materials and very little is written on the testing and examining of materials.

As with the title so with the text. The numerous slight differences in American and British definitions destroy the value of the book as an educator of the student of this country. Nor is the book likely to appeal as a reference book ; it contains little that is not adequately dealt with in any standard work on the subject.

There are, however, several features which are admirable. It is profusely illustrated with line diagrams of excellent draughtsmanship. Exercises and examples are inserted at the most effective point of the text, so that the student can test his ability before proceeding further with the chapter.

Unfortunately for the student there are questions which require either the correction of incorrect statements or the careful selection of a few facts from among many fictions. The author has taken no steps to ensure that the student does not proceed happily unaware that his answers may be other than correct.

The book could be condensed, since several portions are repeated in only slightly different forms. Some chapters, notably one which covers reinforced concrete in thirteen pages, should be expanded or preferably omitted.

It would seem that in ensuring that the book is of maximum benefit to his own students, the author has confined his readers to that limited circle.

R. J. ASHBY

## NEW PUBLICATIONS

AMERICAN INSTITUTE OF MINING AND METALLURGICAL ENGINEERS. "*Proceedings of the Twenty-ninth Conference National Open-Hearth Committee of the Iron and Steel Division, Chicago, Ill. April* 24–26, 1946." Volume 29, 8vo, pp. 342. New York : The Institute.

AMERICAN SOCIETY FOR TESTING MATERIALS. "*1946 Book of A.S.T.M. Standards Including Tentatives.*" 8vo. Part I-A, "*Ferrous Metals.*" Pp. xxiv + 1181 ; Part I-B, "*Non-Ferrous Metals.*" Pp. xxiv + 917 ; Part II "*Nonmetallic Materials—Constructional.*" Pp. xxxviii + 1762 ; Part III-A, "*Nonmetallic Materials—Fuels, Petroleum, Aromatic Hydrocarbons, Soaps, Water, Textiles.*" Pp. xxv + 1290 ; Part III-B, "*Nonmetallic Materials—Electrical Insulation Plastics, Rubber, Paper, Shipping Containers, Adhesives.*" Pp. xxx + 1360. Philadelphia ; The Society (Price $44.00).

BRITISH STANDARDS INSTITUTION. British Standard 970 : 1947. "*Wrought Steels for Use up to* 6 *in. Ruling Section for Automobile and General Engineering Purposes (En. Series).*" (Second Revision, Mar. 1947). 8vo. pp. 156. London : The Institution. (Price 10*s.* 6*d.*).

BRITISH STANDARDS INSTITUTION. British Standard 1344: 1947. "*Methods of Testing Vitreous Enamel Finishes.*" 8vo, pp. 13. London : The Institution. (Price 2*s.*).

CALLAHAM, L. I. "*Russian–English Technical and Chemical Dictionary.*" 8vo, pp. xvii + 794. New York, 1947 : John Wiley and Sons, Inc, ; London : Chapman and Hall, Ltd. (Price $10.00).

CHEVALIER, J. "*Le Creusot.*" 8vo, pp. 300. Bruxelles, 1946 : Editions Baude. (Price 120 francs).

DURRER, R. "*Grundlagen der Eisengewinnung.*" 8vo, pp. v + 210. Illustrated. Bern, 1947 : Verlag Francke, A.-G.

GREGORY, E. and E. N. SIMONS. "*Stainless and Heat-Resisting Steels Simply Explained.*" 8vo, pp. 131. Illustrated. London, 1946 : Hutchinson and Co., (Publishers) Ltd. (Price 8*s* 6*d.*).

MARÉCHAL, J. "*Les Metaux et Alliages.*" 8vo., pp. 300. Paris : Hermann.

MOND NICKEL CO., LTD. "*Nickel Cast Iron for Engineers.*" 8vo, pp. 24. Illustrated. London : The Company.

PAVLOFF, M. A. "*Metallurgy of Iron.*" Part I, "*Introduction, Raw Materials.*" Pp. 207 ; Part II, "*Blast-Furnace Process.*" Pp. 492. Illustrated ; Part III, "*Blast-Furnace Design.*" Pp. 294. Illustrated with Atlas of 28 tables. Moscow, 1947. (In Russian).

RAVIOLI. "*Metodi de Analisi Chimica Siderurgica.*" Milan : Ulrico Hoepli. (Price 1200 Lire).

RAYNOR, G. V. "*An Introduction to the Electron Theory of Metals.*" (Institute of Metals Monograph and Report Series No. 4). 8vo, pp. x + 98. Illustrated. London, 1947 : The Institute of Metals. (Price 7*s.* 6*d.*).

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VOL. 156 PART 4

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The Iron Ores of Germany . . *by A. E. Lance*

The Mechanism of Corrosion-Fatigue of Steel in Acid Solution . . *by M. Tchorabdji Simnad and U. R. Evans*

Report of the Annual General Meeting, 1947

Discussion on papers presented at the Annual General Meeting

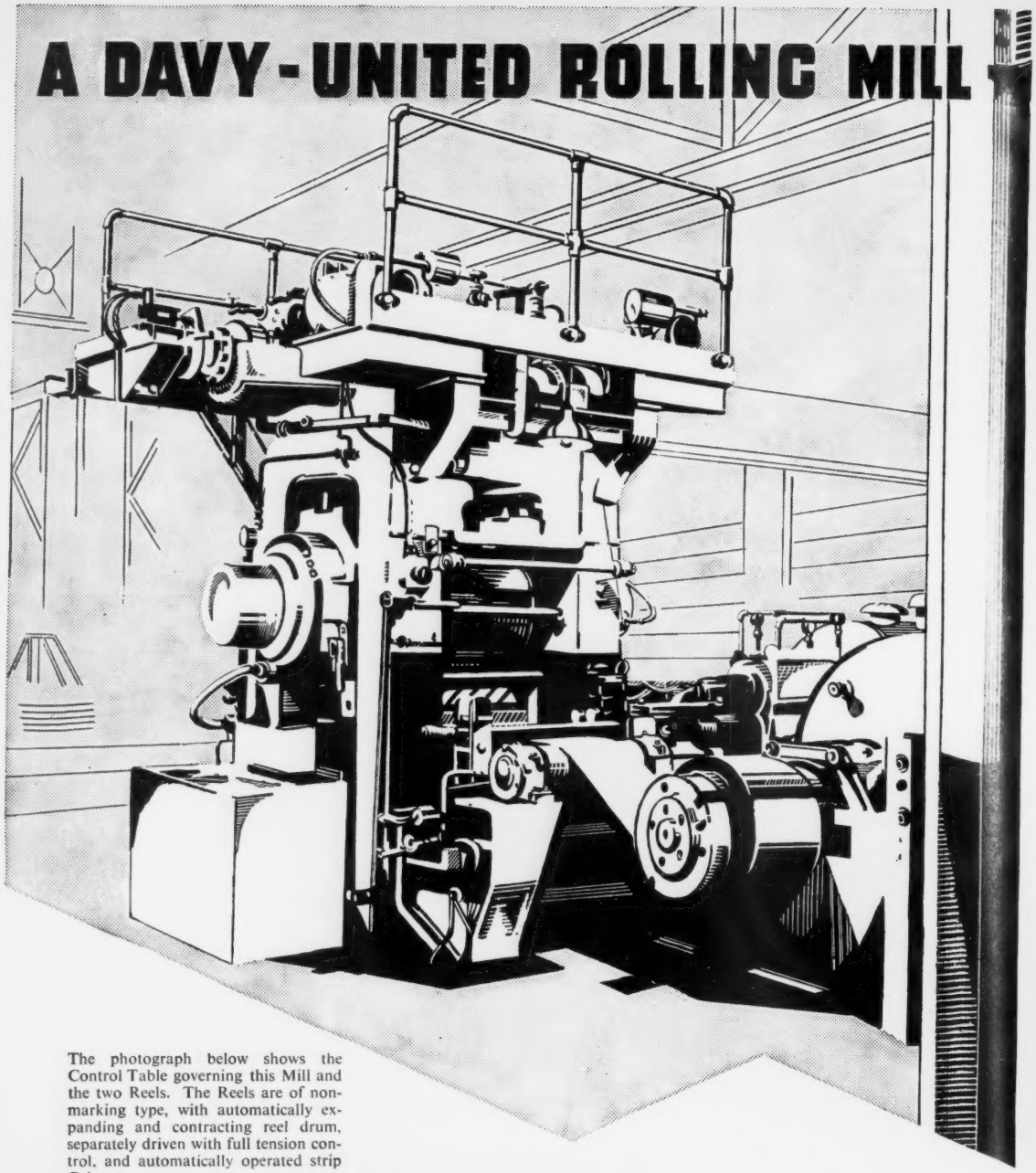
Correspondence

General discussion on Steam Turbines and Water-Tube Boilers

News and Abstracts

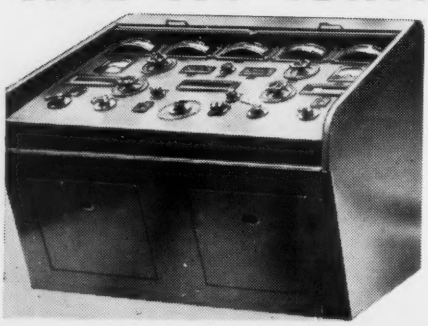
*A full list of Contents is given on the Title Page* (see *page* 31, *Advertisement Section*).

# A DAVY-UNITED ROLLING MILL



The photograph below shows the Control Table governing this Mill and the two Reels. The Reels are of non-marking type, with automatically expanding and contracting reel drum, separately driven with full tension control, and automatically operated strip Gripper.

# AND ITS CONTROL ASSEMBLY



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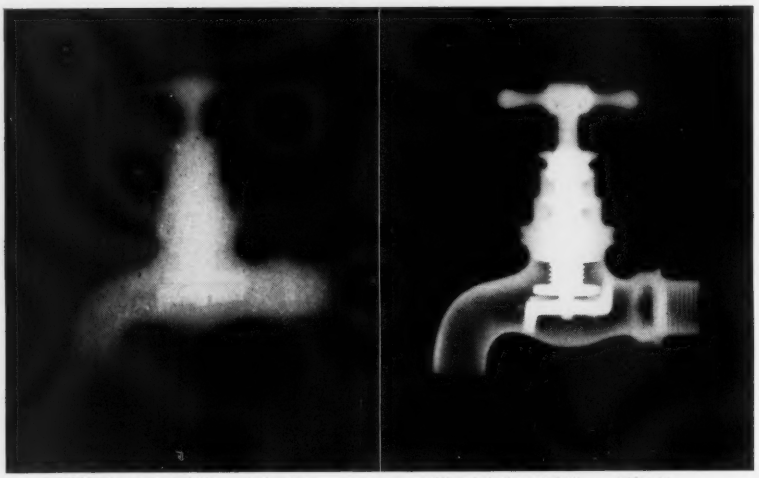

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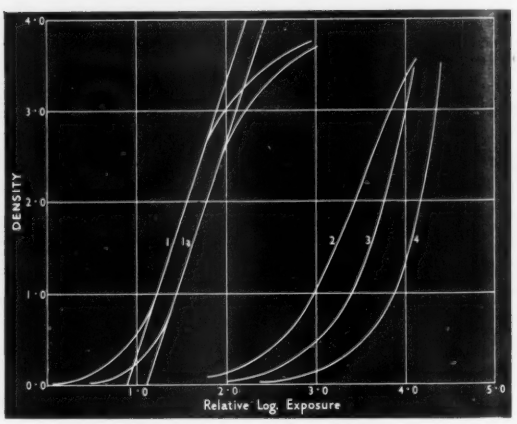


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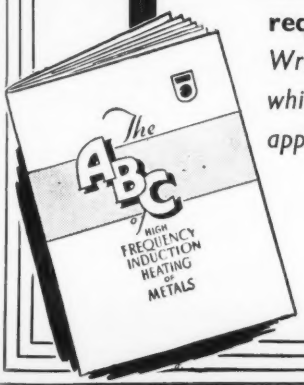


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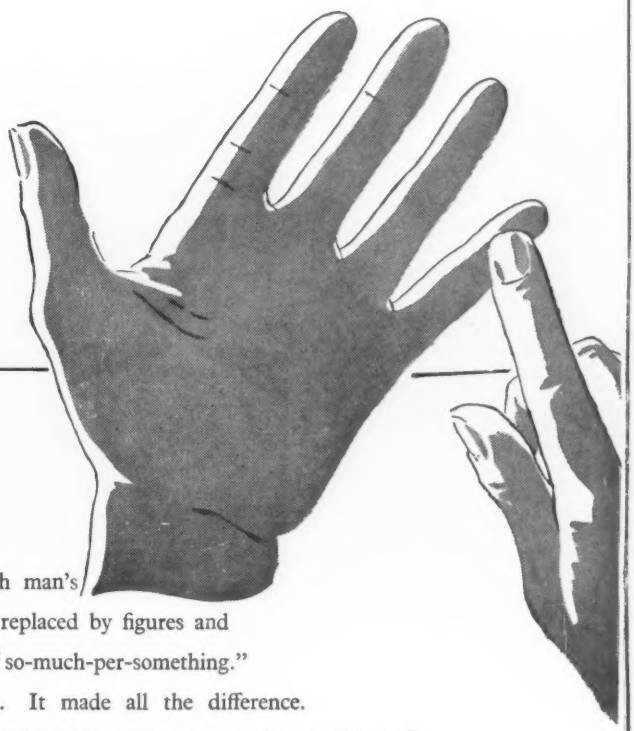

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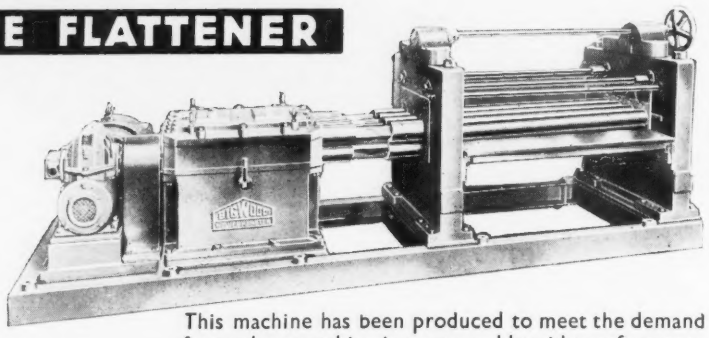

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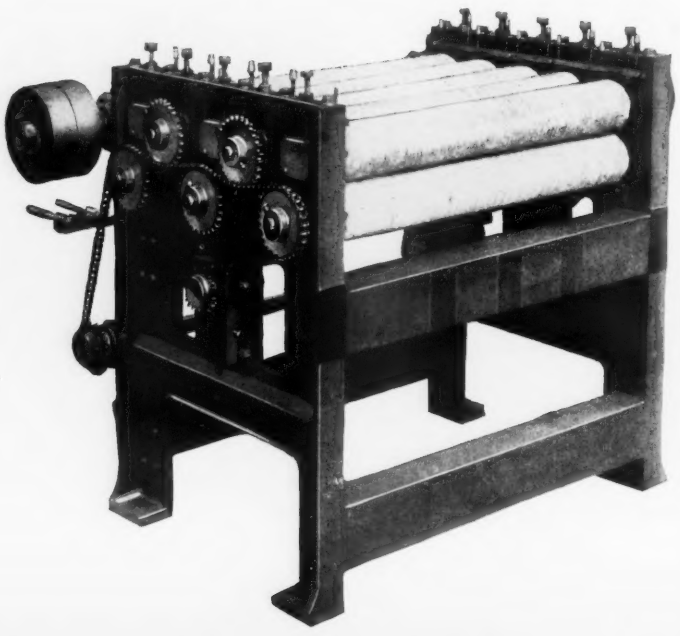

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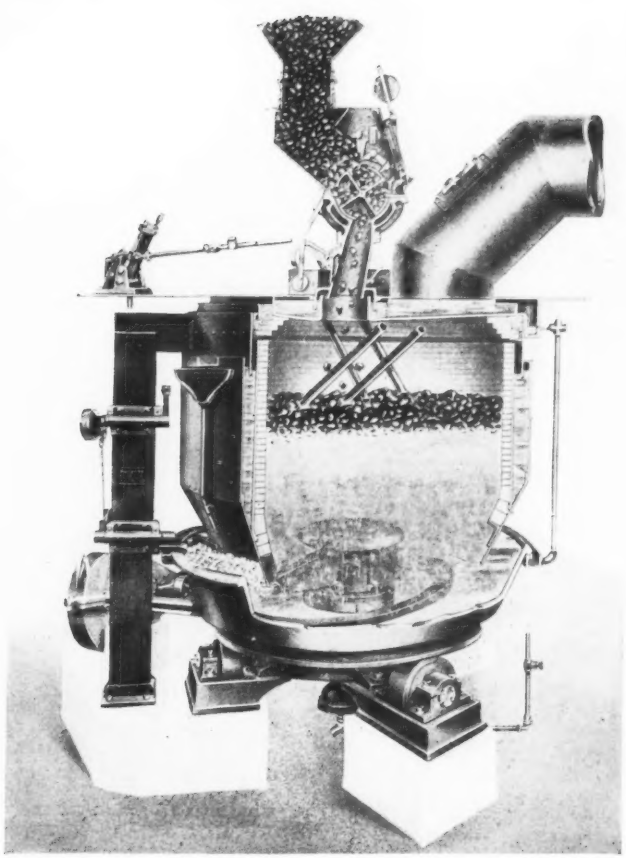

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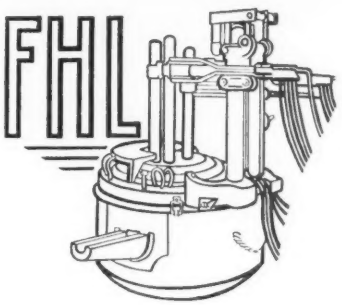


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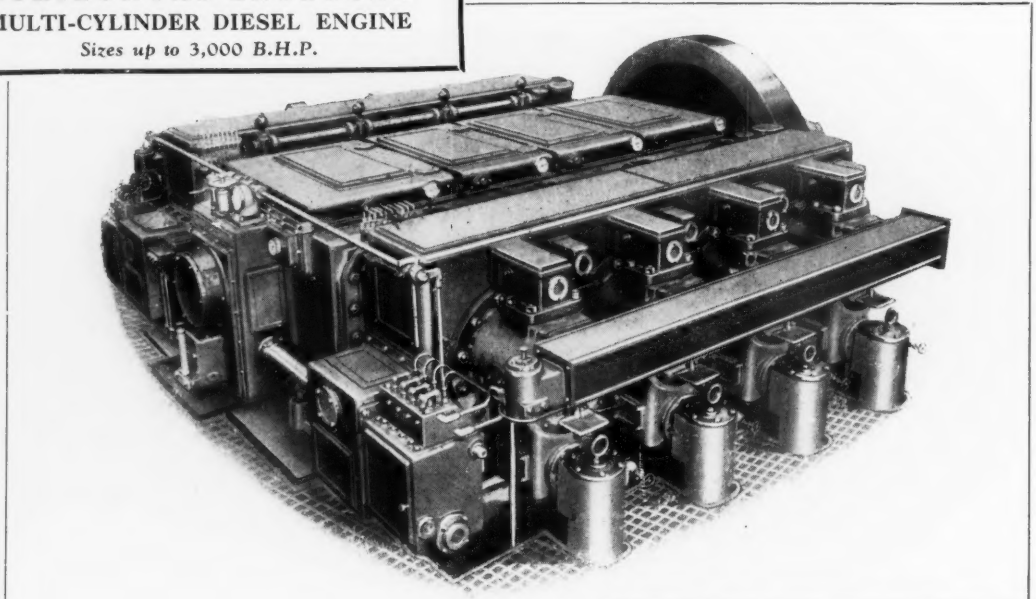

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# BLAW-KNOX

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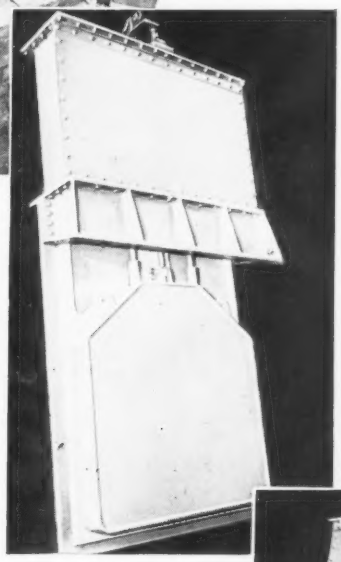

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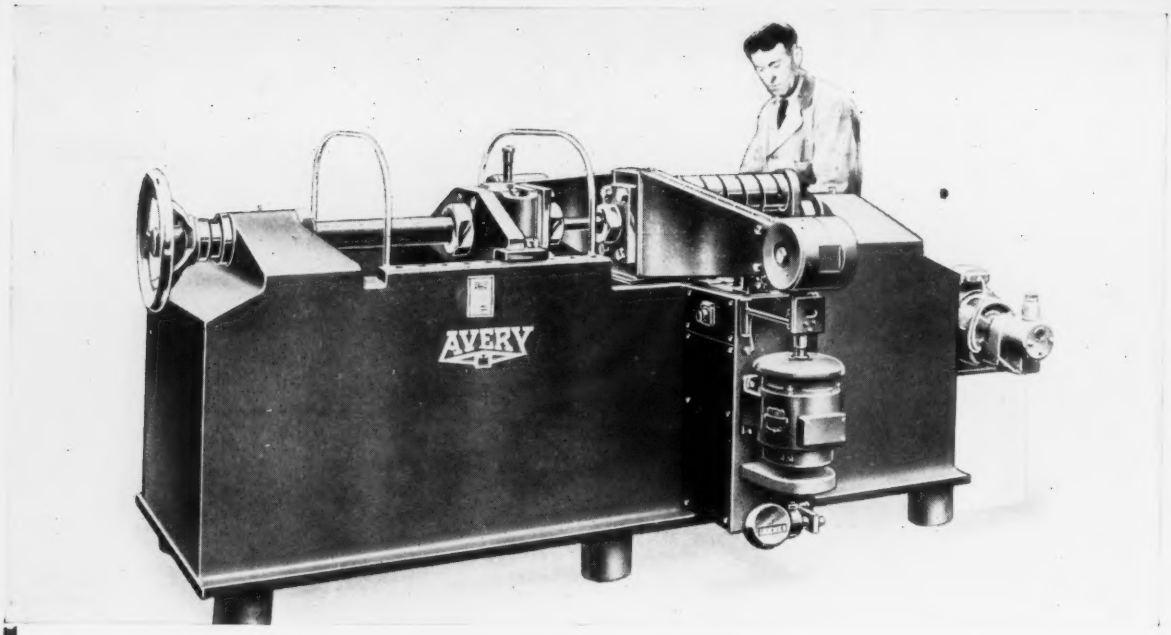


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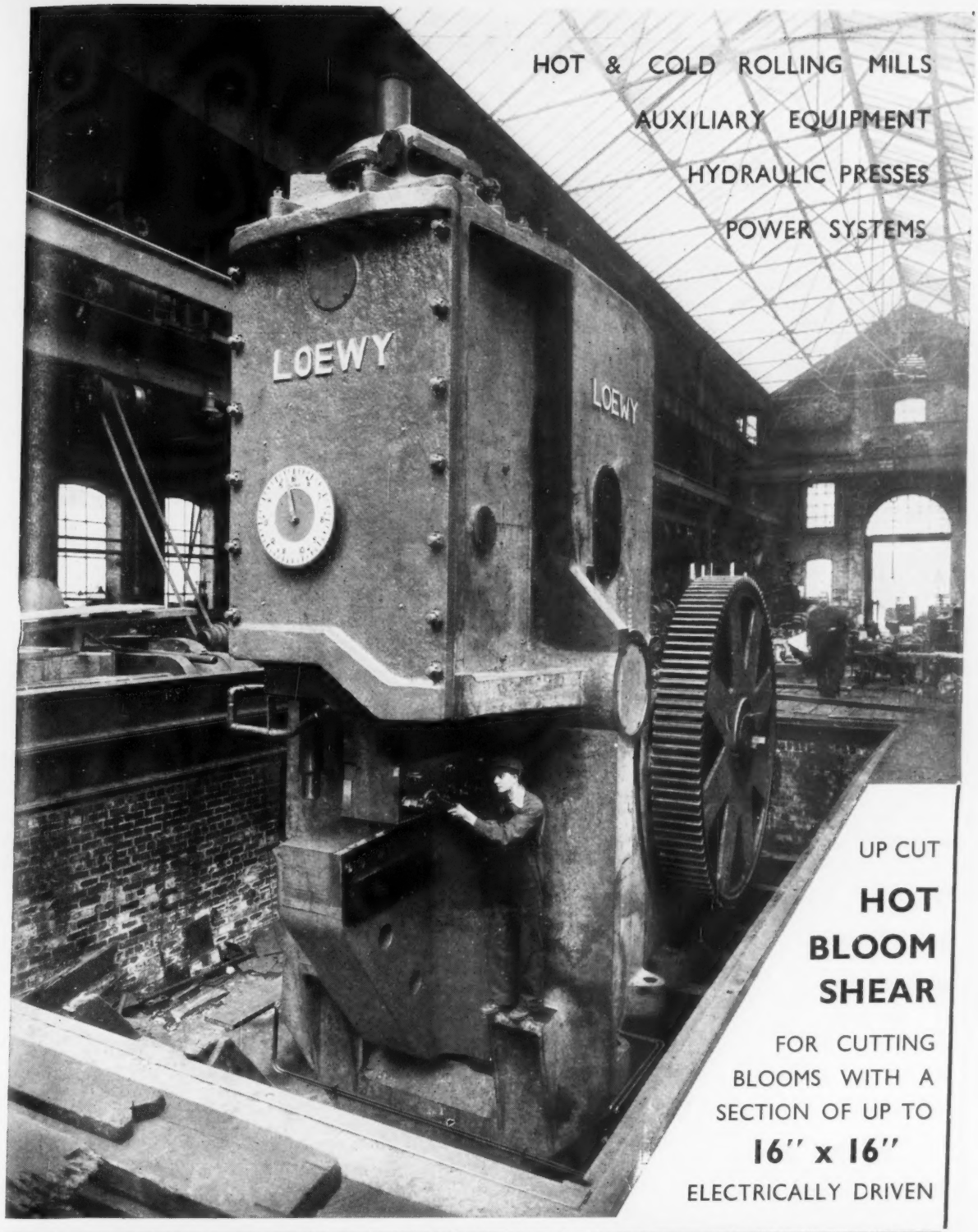


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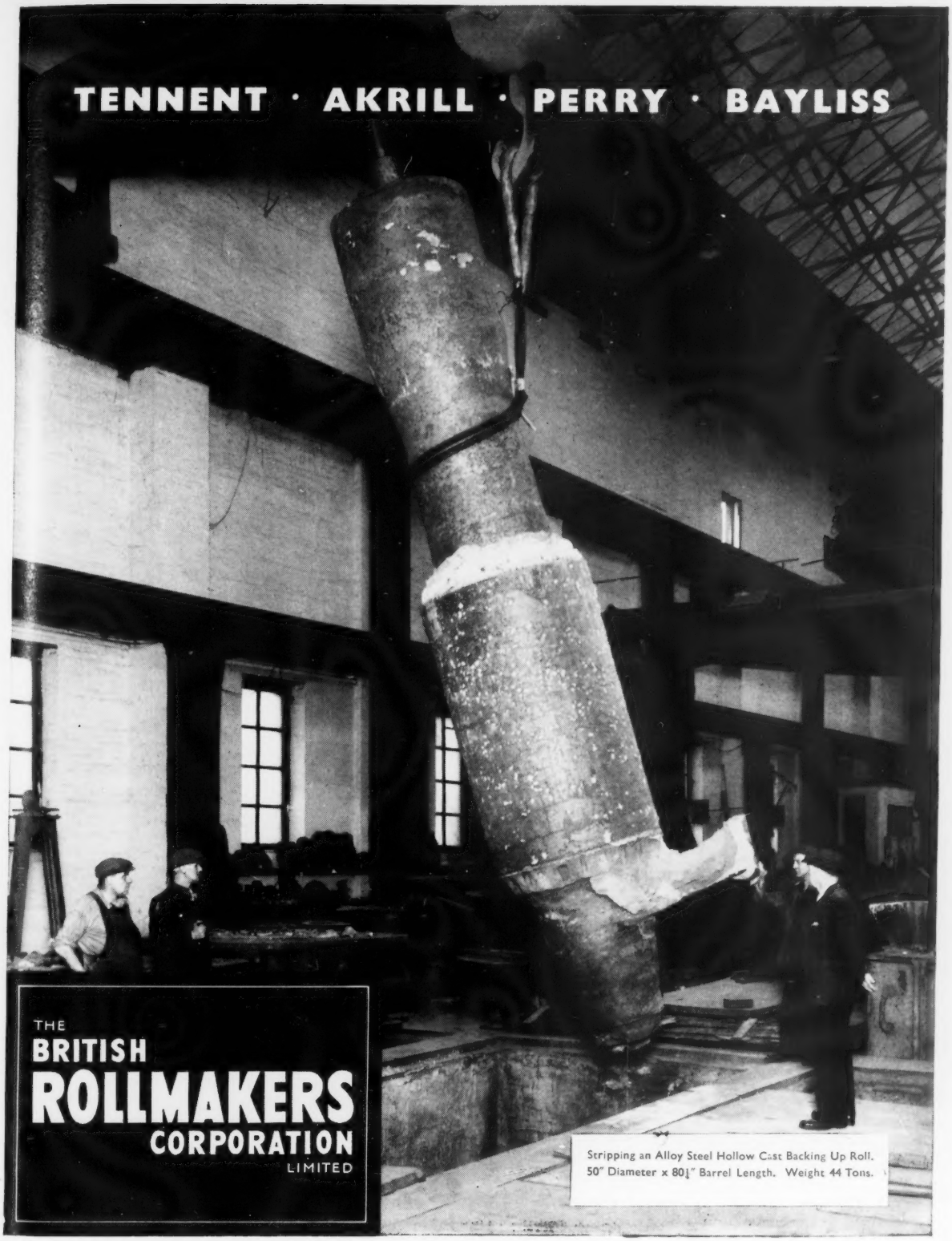


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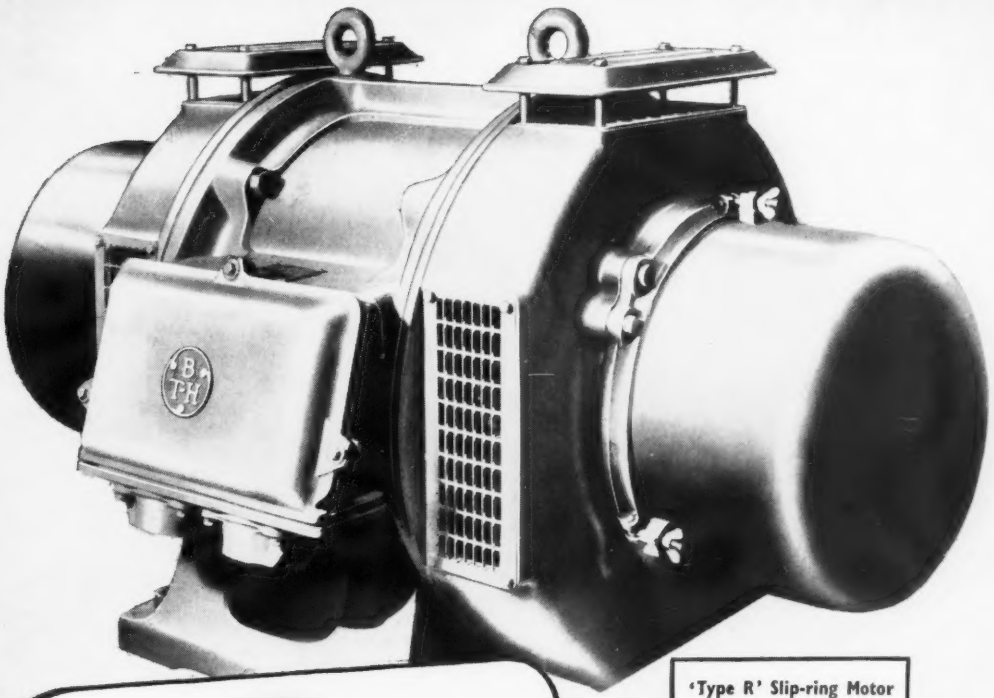

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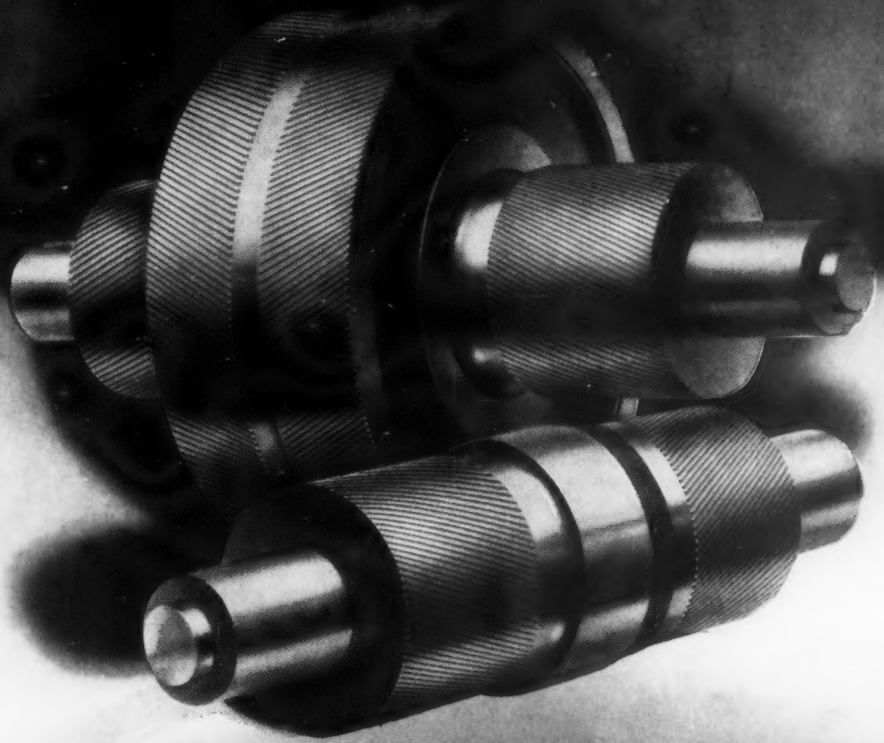

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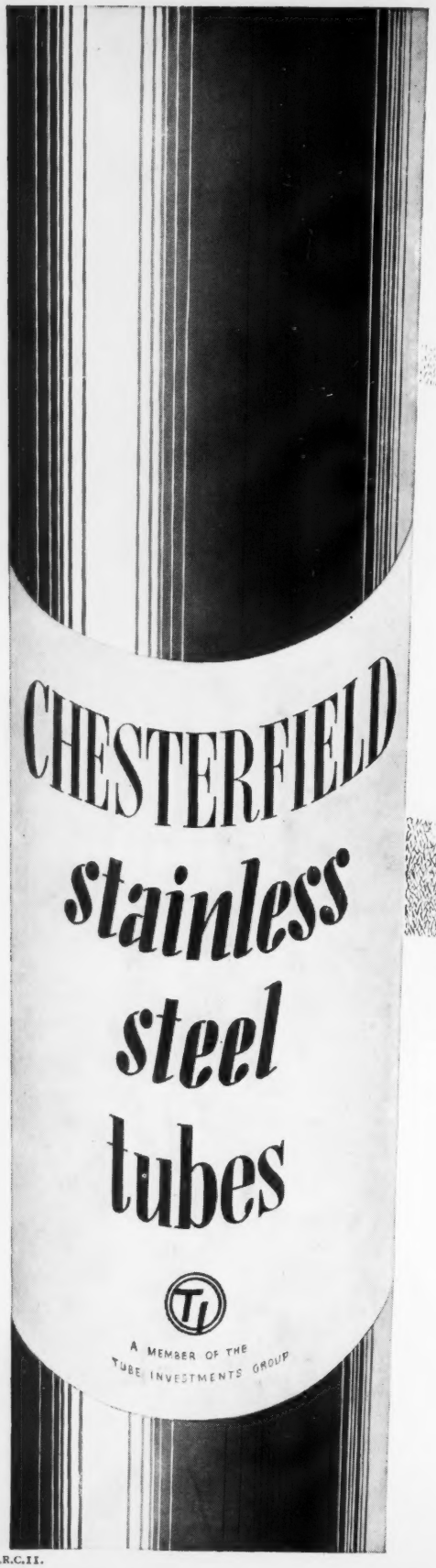


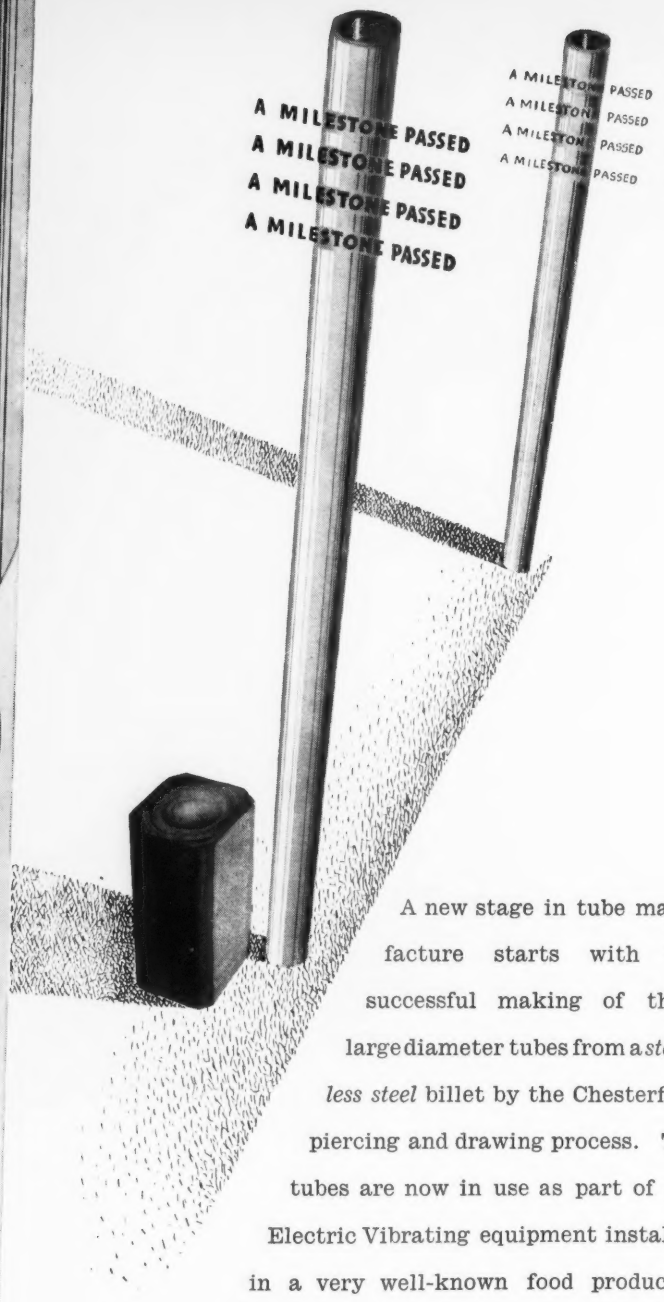


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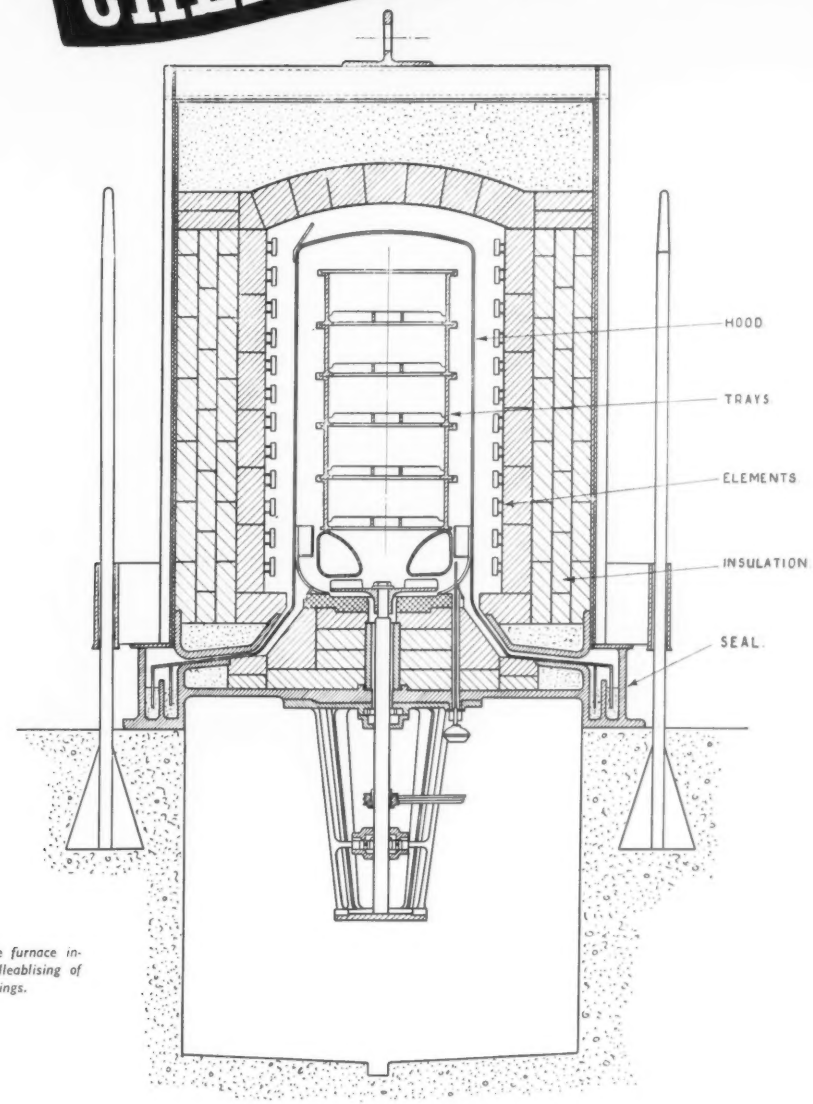


*Diagram of Bell type furnace installation for the malleablising of small white heart castings.*

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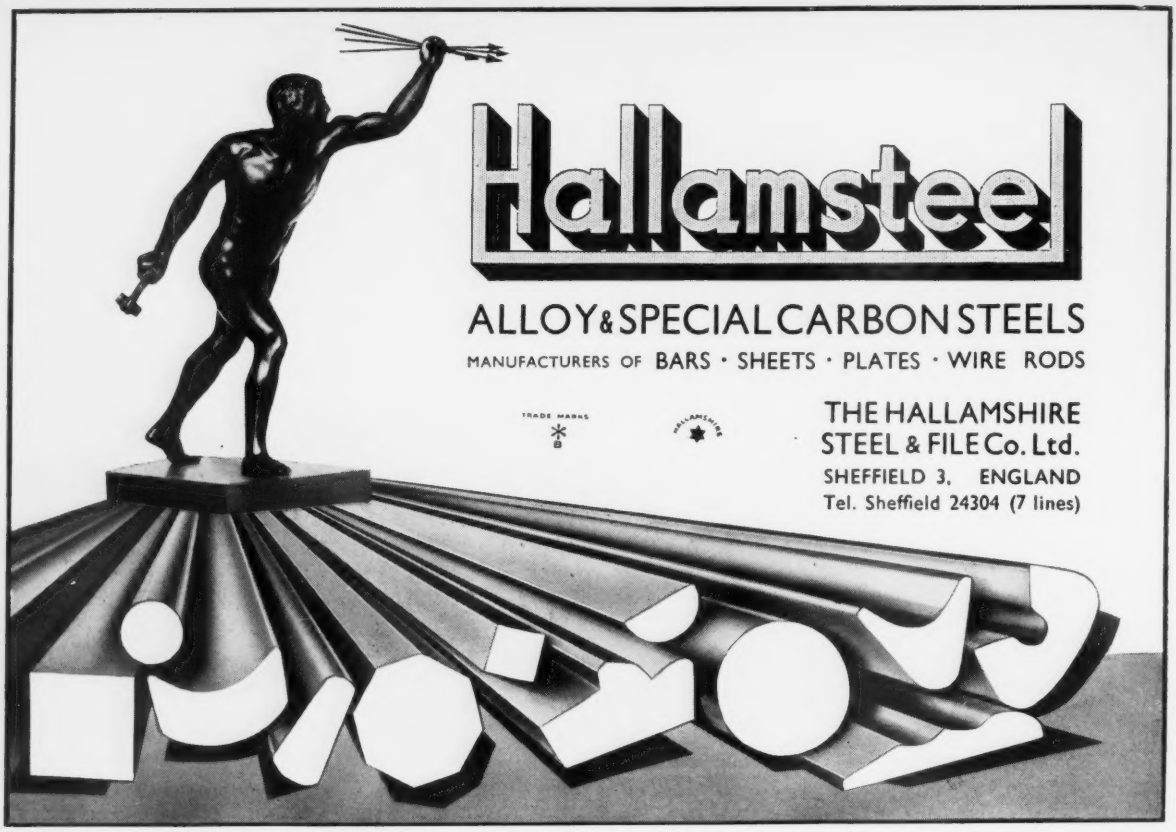

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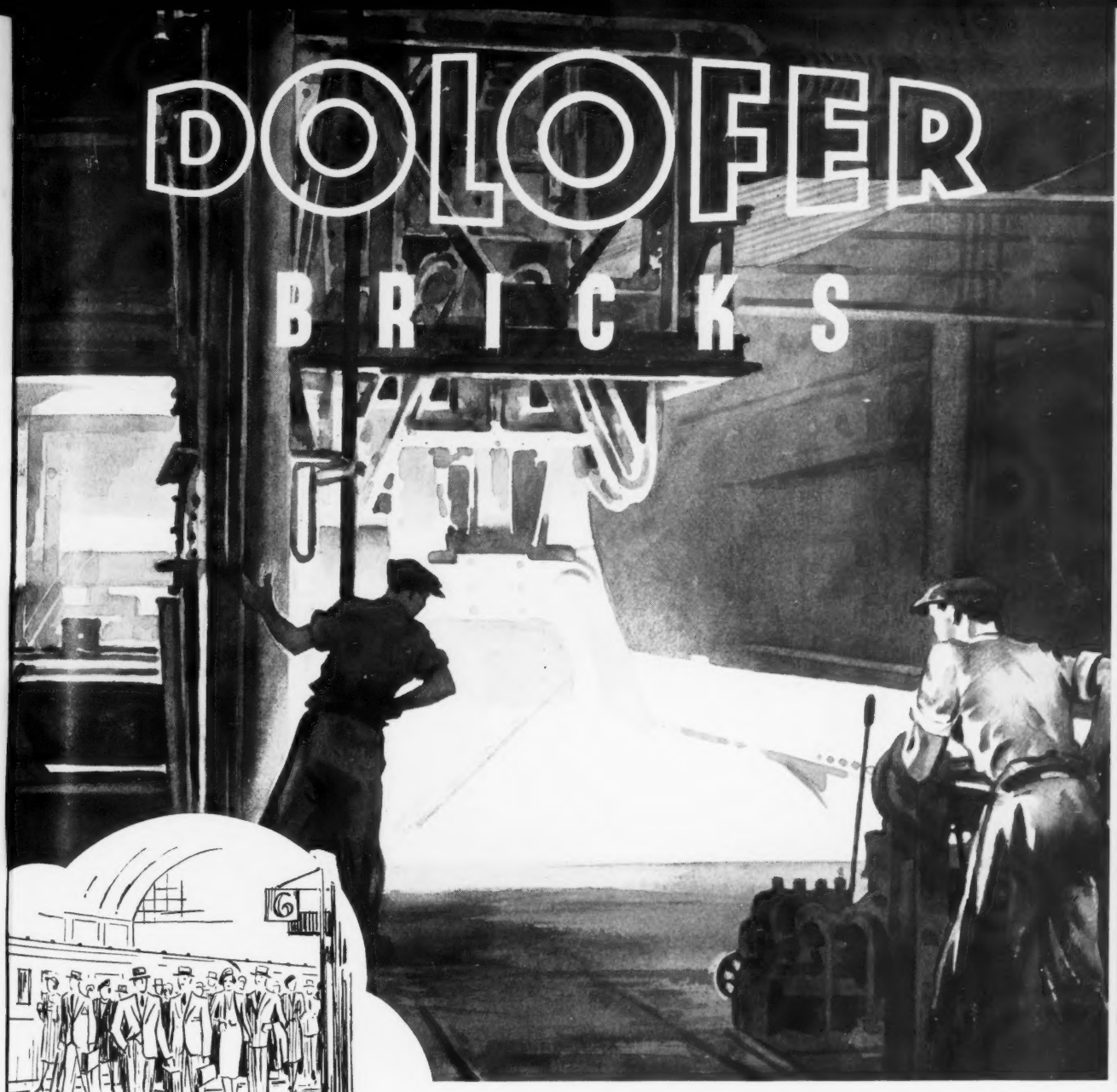


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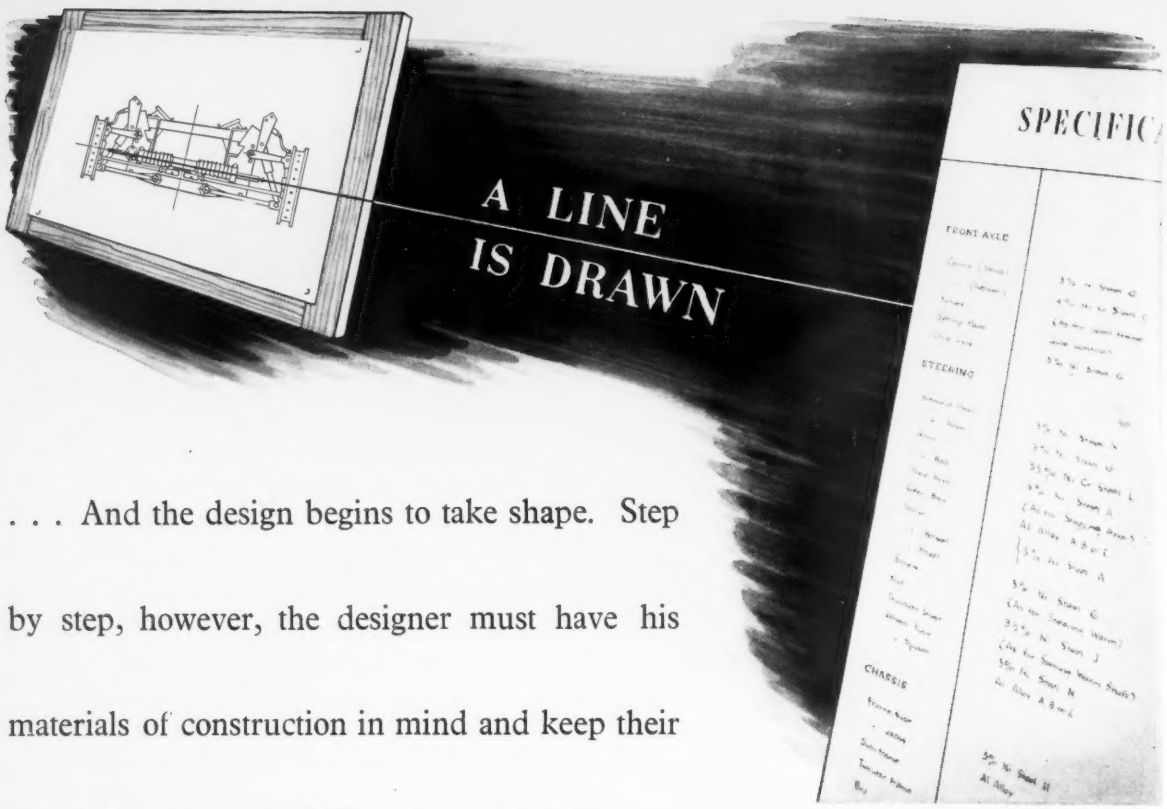


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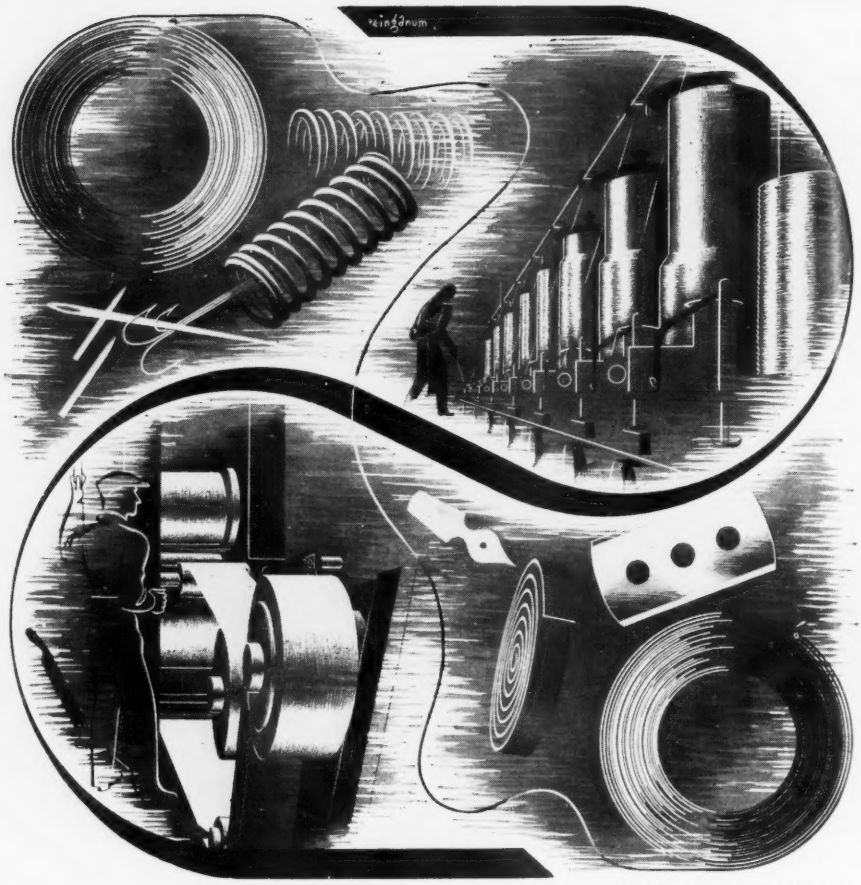


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